# EFFECTS OF SEX AND SIRE LINE ON RELATIONSHIPS AMONG EARLY POSTMORTEM LOIN QUALITY AND AGED LOIN AND PORK CHOP QUALITY CHARACTERISTICS

BY

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DISSERTATION

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## ABSTRACT

Pork is the most consumed animal protein in the world. A primary goal of packers is to increase consumer satisfaction and purchase intent by providing a visually appealing product and a quality eating experience. Rapid assessment of pork quality by packers necessitates using early postmortem (~1 d) traits as an indication of aged pork quality (~14 d). Packers assess quality on a different surface and at a different time than consumers. Therefore, it is unknown if quality traits translate between the packer and the consumer. Carcass characteristics and meat quality are influenced by both intrinsic (sex and genotype) and extrinsic (environmental) factors. Failure to control these factors makes it difficult to separate true differences associated with sex or genotype from those associated with the environment. Furthermore, relationships between early and aged quality traits of pork loins may be influenced by differences in quality traits between sex or genotype. Therefore, the objectives were: 1) Determine correlations between early postmortem loin quality and aged loin and chop quality characteristics, 2) Determine if correlations between early and aged loin quality differ between barrows and gilts, 3) Control both inherent and environmental factors in order to determine specific effects of sire line on growth and carcass characteristics, fresh belly quality, and commercial bacon slicing yields, and 4) Determine if correlations between early postmortem loin quality and aged loin and chop quality differ between pigs sired by either Pietrain or Duroc boars.

For the first two objectives, Early postmortem (~1 d) quality traits included: instrumental and subjective color, marbling and firmness, and loin pH on the ventral surface of the loin. Loins were aged until 14 d postmortem in vacuum packages. Aged quality traits included traits evaluated early postmortem as well as Warner-Bratzler shear force and cook loss. Correlations were compared between barrows and gilts using a Fisher's z test. In both barrows (B) and gilts

(G), early pH was correlated with subjective ventral color (r = 0.55, B; 0.41 G) and subjective chop color (r = 0.42 B; 0.44 G). Early lightness (L*) was correlated with aged L* (r = 0.60 B; 0.51 G). Early marbling was correlated with chop marbling (r = 0.57 B; 0.59 G). Correlations rarely differed between barrows and gilts and sex does not need to be accounted for when relating early and aged quality characteristics.

To test the third and fourth objectives, a total of 320 barrows and gilts were used. Offspring shared a common dam line and all environmental contributions to variation were controlled. Pigs were housed in single-sex pens by sire line. Pigs were slaughtered at the end of a 98 d feeding program. There were no differences in growth performance or belly processing characteristics ($P \geq 0.08$). Pietrain sired pigs had a greater lean yield ($P \leq 0.01$). Duroc sired pigs had darker, more highly marbled loins ($P \leq 0.04$) and thicker bellies ($P < 0.001$). Bacon from Pietrain sired pigs had a greater ($P = 0.04$) lean to fat ratio with a 1.58% increase ($P = 0.04$) in average bacon slice lean.

Early and aged quality traits measured were the same as the first two. Correlations were compared between Pietrain and Duroc-sired pigs using a Fisher's z test. Early ventral visual color was correlated with aged chop L* (Pietrain r = 0.46; Duroc r = 0.60) and aged chop visual color (Pietrain r = 0.45; Duroc r = 0.57). Early visual marbling was correlated (Pietrain r = 0.68; Duroc r = 0.84) with aged chop visual marbling. No early postmortem quality traits were correlated ($|r| \leq 0.34$) with WBSF or cook loss for either sire line. In summary, correlations between early and aged quality traits rarely differed between Duroc and Pietrain-sired pigs. It is not necessary to account for sex or sire line when relating early and aged quality characteristics.

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# Chapter 1

# REVIEW OF LITERATURE

## INTRODUCTION

Pork is the most consumed animal protein in the world (Pork Quick Facts, 2014; National Pork Board, 2017), and consumer needs and expectations of both visual and eating quality contribute significantly to the purchase and consumption of pork (Moeller et al., 2010). Both packers and consumers use similar traits to evaluate pork quality, however, the surface they assess and time postmortem when they make those assessments differ. Unlike beef carcasses, pork carcasses are not routinely ribbed (cut between the $10^{th}$ and $11^{th}$ rib to expose the longissimus muscle) in the U.S. Therefore, packers estimate quality on the ventral surface of a boneless loin after carcass fabrication at 1d postmortem (King et al., 2011). Alternatively, consumers commonly purchase pork chops or other cuts rather than whole, intact pieces (King et al., 2011). Pork products are often stored at 0° C and may be held for up to 3 weeks before being made available for consumer purchase (Ngapo et al., 2012). Therefore, consumers are often assessing quality on the cut surface of loin chops after a period of aging. Postmortem proteolysis occurs during the aging process or storage of pork (Huff-Lonergan et al., 2002; Lonergan et al., 2010). Ventral quality estimates are used to select loins for different premium based programs or export markets based on individual consumer demand. For example, visible fat is the strongest visual quality cue for U.S. consumers while Mexican consumers prefer a product that is more lean (Brewer et al., 2001; Ngapo et al., 2017). The term “quality” is rather ambiguous as emphasis placed on specific quality traits differs among consumers (Moeller et al., 2010; Murphy et al., 2015). However, eating quality and repeat purchase intent are usually determined by both the tenderness and juiciness of the cooked chops (Moeller et al., 2010). Overall quality is influenced by postmortem proteolysis as it contributes to changes in both visual color and tenderness (Huff-Lonergan et al., 2002; Lonergan et al., 2010). Aside from aging, pork quality can also be influenced by congenital traits such as sex and genotype of pigs (Klont et al., 1998; Overholt et al., 2016).

Pork quality differences between barrows and gilts, as well as between different genotypes have been well documented (Martel et al., 1988; Klont et al., 1998). However, how these differences contribute to relationships among early and aged postmortem quality is unclear. A primary goal of producers and packers is to increase consumer satisfaction and purchase intent by providing them both a visually appealing product and a quality eating experience. One area of interest is determining if the early postmortem quality traits observed by packers are related to aged quality traits observed by consumers. A second area of interest is if packers need to account for sex or genotype of pigs when selecting loins to meet specific consumer demands. The objectives of this body of work were: 1) Determine correlations between early postmortem loin quality and aged loin and chop quality characteristics; 2) Determine if correlations between early postmortem loin quality and aged loin and chop quality differ between barrows and gilts; 3) Determine if correlations between early postmortem loin quality and aged loin and chop quality differ between pigs sired by either Pietrain or Duroc boars. It is expected that established loin quality differences between sex and genotype will affect how loins age, which will result in correlation differences between barrows and gilts, and between Pietrain and Duroc-sired pigs.

**PORK QUALITY**

Pork quality is multifaceted, affected by many factors, and defined differently based on consumer preference. Color, juiciness, marbling, tenderness, and flavor are traits which contribute differently to how a consumer evaluates pork quality and the emphasis placed on each trait varies based on individual preference (Moeller et al., 2010; Murphy et al., 2015). In the U.S., color and marbling are two visual loin quality traits most influential to consumer purchasing decisions (Moeller et al., 2010) but, tenderness is often cited as the most important for eating experience (Moeller et al., 2010).

***Ultimate pH***

Ultimate pH was significantly correlated with several meat quality characteristics and therefore, pH measurements are commonly used to predict those quality attributes important to consumers (Huff-Lonergan et al., 2002; Richardson et al., 2018). Most important is visual color which drives initial purchase intent more than any other quality trait (Mancini and Hunt, 2005). Color was directly influenced by water-holding capacity (**WHC**) and ultimate pH was significantly correlated with both (Huff-Lonergan et al., 2002; Bee et al., 2007). The ultimate pH of pork relates to the amount of glycogen present at the time of slaughter (Huff-Lonergan et al., 2002). Type of muscle fiber influences ultimate pH as the amount of glycogen and glycolytic capacity differs between the muscle fiber types (Choi et al., 2006). Glycolytic fibers (white, fast-twitch fibers) have a greater glycogen content, and greater amounts of glycogen in the muscle tissue at slaughter results in a greater postmortem decrease in pH through rapid glycolysis and accumulation of lactate (Monin and Sellier, 1985; Choi et al., 2006). As ultimate pH decreases WHC decreases, increasing surface light reflectance or scattering of light (Hamm, 1961). It is this scattering of light that causes the color of meat to appear either light or dark to the human eye. Therefore, meat with a decreased ultimate pH appears lighter in color or more pale because it reflects or scatters more light back to the observer (Swatland, 2008). Proportion of glycolytic fiber types is influenced by both sex, and genetic selection for lean growth (Solomon et al., 1990; Chang et al., 2003). Both gilts and lean breed types, such as Pietrains, tend to have a greater proportion of glycolytic fiber types relative to oxidative fiber types (Solomon et al., 1990; Chang et al., 2003). Additionally, a greater glycolytic potential has been reported in muscles of gilts compared with barrows (Larzul et al., 1997). With a greater glycolytic potential, one would expect ultimate pH to be less in muscle from gilts. Indeed, several studies have reported that loin pH was lesser in gilts than in barrows (Larzul et al., 1997; Souza and Mullan, 2002; Overholt et al., 2016) however, other studies report no difference in loin pH between the two sexes (Cisneros et al., 1996; Latorre et al., 2003; Boler et al., 2014; Lowell et al., 2017a). It has also been reported that ultimate pH is greater in meat quality breed types, such as Durocs, compared with lean breed types, such as Pietrains (Klont et al., 1998; Chang et al., 2003; Edwards et al., 2003). Altered fiber type composition is most likely due to genetic selection for lean growth which resulted in a greater proportion of glycolytic fibers and a reduced frequency of oxidative fibers (Klont et al., 1998). Differences in proportions of muscle fiber types also influence color as myoglobin is less abundant in glycolytic fiber types (Newcom et al., 2004).

***Color***

The color of pork relates to the structure and quantity of myoglobin (MacDougall, 1994). Myoglobin is the primary pigment of meat and has three main states in which it can exist; deoxymyoglobin, oxymyoglobin, and metmyoglobin (Cornforth, 1994). The state of myoglobin is determined by the state of the iron, ferrous ($Fe^{2+}$) or ferric ($Fe^{3+}$), as well as the oxygenation of myoglobin (Lawrie, 2006). In fresh meat, before cooking, the most important chemical form is oxymyoglobin (Lawrie, 2006). Consumers desire a bright red color when purchasing products and, as mentioned before, meat purchasing decisions are influenced by color more than any other quality trait (Mancini and Hunt, 2005). This is because consumers associate color with both freshness and wholesomeness of products (Mancini and Hunt, 2005). Myoglobin is the principle protein responsible for meat color (Mancini and Hunt, 2005). The amount of myoglobin present in muscle is associated with the proportion of oxidative muscle fibers (red, slow-twitch fibers) (Joo et. al., 2013). An increase in the proportion of oxidative fibers tends to decrease lightness (L*) and increase redness (a*), improving overall visual quality (Klont et al., 1998; Joo et al., 2013). Conversely, an increase in glycolytic muscle fibers tends to increase L* and decrease a* (Joo et al., 2013). As previously discussed, the proportion of glycolytic fibers is influenced by both sex and genetic selection (Solomon et al., 1990; Chang et al., 2003). Reported differences in both L* and a* between sexes would support this difference in proportion of muscle fiber types (Overholt et al., 2016) however, there are others studies that have reported no differences in L* and a* between sex (Correa et al., 2006; Boler et al., 2014). As a result of genetic selection, meat quality breed types have a greater proportion of oxidative muscle fiber types and produce loins that are visually darker compared with lean breed types (Ellis et al., 1996; Chang et al., 2003; Edwards et al., 2003). It has also been reported that loins from meat quality breed types, such as Durocs, have a lower L* and a greater a* than lean breed types, like Pietrains (Edwards et al., 2003). In addition to differences in muscle fiber types, genetic selection for meat quality characteristics has also influenced amount of intramuscular fat or visual marbling (Chang et al., 2003).

***Marbling (Intramuscular Fat)***

Along with the color of pork loins influencing purchasing decisions, the amount of marbling or intramuscular fat (**IMF**) content is another factor consumers regularly use to access the value and quality of pork products (Levy and Hanna, 1994; Brewer et al., 2001). Intramuscular fat is one of two types of fat deposits located within the muscle and is deposited in loose networks of perimysial connective tissue in close proximity to blood vessels (Aberle et al., 2001). The amount of IMF can be altered one of two ways: manipulation through the diet during the growing phase, and/or breed substitution and selection technologies (Olivares et al., 2009). However, genotype plays a greater role in IMF deposition than diet (Souza et al., 2003; Olivares et al., 2009). Indeed, as producers continue to modify breeding objectives to meet changing consumer demands, they have established both a lean growth breed type (Pietrain) and a meat quality breed type (Duroc). Meat quality breed types have more IMF and extractable lipid compared with lean growth breed types (Ellis et al., 1996; Arkfeld et al., 2016). There is also a difference in the amount of IMF between barrows and gilts however, the difference between sexes is due to the rate of maturity rather than genotype, in pigs of the same breed (Lee et al., 2013). There is some evidence that the amount of IMF present within the muscle is related to the proportion of different muscle fiber types (Essen-Gustavsson et al., 1994; Aberle et al., 2001). The relationship between genotype and muscle fiber type explains the difference in IMF between the lean growth and meat quality breed types. Meat quality breed types have a greater proportion of oxidative muscle fibers and there is a positive linear relationship between the proportion of oxidative fiber types and amount of IMF (Essen-Gustavsson et al., 1994). Marbling is often credited with improving sensory characteristics and many consumers consider marbling to be indicative of overall eating experience including tenderness, juiciness, and flavor (Aberle et al., 2001; Rincker et al., 2008). However, current data indicates that marbling may not actually influence sensory characteristics as much as consumers believe it does (Rincker et al., 2008; Wilson et al., 2017).

***Pork Sensory: Tenderness, Juiciness, and Flavor***

The ultimate goal of pork producers and packers is to maintain pork's competitive advantage as a protein source through increased consumer satisfaction and purchasing of products (Moeller et al., 2010). Palatability or eating quality, a culmination of tenderness, juiciness, and flavor, is an important factor that influences choice of protein source at the consumer level (Moeller et al., 2010). Fresh color and marbling are used by consumers as indicators for tenderness and juiciness (Wood et al., 2004; Lonergan et al., 2007). Therefore, the pork industry continues to place emphasis on both color and marbling in order to predict tenderness, juiciness, and flavor. However, current research indicates that overall eating quality (tenderness, juiciness, and flavor) is not as dependent upon visual quality (color and marbling) as consumers believe (Rincker et al., 2008; Wilson et al., 2017; Richardson et al., 2018). In fact, visual color and marbling explain less than 1% of the variation in sensory tenderness, juiciness, and flavor (Wilson et al., 2017; Richarson et al., 2018). Therefore, color and marbling are not effective predictors of overall eating quality however, it has been determined that overall eating quality is much more reliant upon endpoint cooking temperature (Rincker et al., 2008; Wilson et al., 2017; Richardson et al., 2018). Historically, it had been recommended to cook pork to an internal temperature of 71 $^{o}$C in order to control postharvest consumer exposure to *Trichinella spiralis* (Lien et al., 2002). However, modern pork production has changed radically over the last 10 years with advances in housing, diet, management, and biosecurity (Davies et al., 1997). These changes have drastically reduced the incidence of infectious diseases and parasites thus, it is no longer necessary to cook pork to such a high degree of doneness (Davies et al., 1997). Additionally, multiple studies have evaluated the effects of lowering endpoint cooking temperature on the tenderness, juiciness, and flavor of whole muscle cuts of pork; as endpoint temperature is decreased, overall eating quality is improved (Rincker et al., 2008; Moeller et al., 2010). Because of advances in swine production as well as the influence of cooking temperature on eating quality, the National Pork Board decreased the recommended cooking temperature of pork from 71 $^{o}$C to 63 $^{o}$C. Regardless, color and marbling are still considered important visual quality traits and consumers continue to use them when making purchasing decisions (Mancini and Hunt, 2005). While the desired quality may fluctuate depending on the intended consumer, it is vital that the pork industry continues to provide them with a positive eating experience.

## GROWTH AND QUALITY CHARACTERISTICS OF BARROWS AND GILTS

Together, barrows and gilts make up approximately 97% of federally inspected hog slaughter, in the U.S. (USDA, 2017), and differences in growth and quality traits between barrows and gilts are well documented (Martel et al., 1988; Overholt et al., 2016). Sex of pig has an effect on both composition and quality of pork carcasses, which can influence quality traits of fresh pork products such as pork loins and chops (Overholt et al., 2016). Sex of the pig also influences the variability of pork carcass composition and quality traits (Overholt et al., 2016).

### *Growth and carcass characteristics*

Barrows often to grow and reach physiological maturity at a faster rate than gilts (Lee et al., 2013). Barrows have both a greater ADFI and ADG compared with gilts however; gilts tend to have a greater feed efficiency than barrows (Latorre et al., 2013; Lowell et al., 2017a). Barrows usually have a greater HCW than gilts when slaughtered at the same age (Lee et al., 2013). However, dressing percent does not tend to differ between barrows and gilts whether slaughtered at the same age or same body weight (Cisneros et al., 1996; Lowell et al., 2017a). Back fat thickness is greater in barrows and carcasses from barrows are fatter, resulting in a decreased bone-in carcass cutting yield, bone-in lean cutting yield, and boneless cutting yield when compared with carcasses from gilts (Lee et al., 2013; Boler et al., 2014). Gilts also produce heavier Canadian back loins that yield a greater percentage of estimated carcass lean (Friesen et al., 1994; Cisneros et al., 1996; Lowell et al., 2017b), and have a larger loin eye area (Bruner et al., 1958; Cisneros et al., 1996) compared with barrows.

***Meat quality characteristics***

Overall, there are very few reported differences in meat and eating quality between barrows and gilts. However, because barrows are fatter than gilts, traits associated with carcass fatness tend to differ between the two sexes. Loins from barrows tend to have greater visual marbling and extractable lipid compared with loins from gilts (Nold et al., 1999; Latorre et al., 2003). Intramuscular fat deposits are positively correlated with age (maturity) and are the last fat deposits to develop (Aberle et al., 2001).  Barrows reach maturity at a greater rate and therefore, begin to deposit intramuscular fat earlier than gilts (Lee et al., 2013).

There are very few reports that loin L* differs between barrows and gilts (Latorre et al., 2003; Lowell et al., 2017b) however, the majority of studies report no differences in L* values between loins from the two sexes (Correa et al., 2006; Gispert et al., 2010; Boler et al., 2014; Lowell et al., 2017a). It is possible that marbling may have an effect on differences in L* value. The American Meat Science Association meat color measurement guidelines recommend that instrumental color (L*, a*, b*) should be measured on a lean surface, free from intramuscular fat or connective tissue (AMSA, 2007). As marbling is increased, it may become more difficult to find a lean surface that is free from fat, and that is representative of the whole sample. However, the difference in L*, may also be due to differences in type of device and illuminant used or differences in muscle fiber types between sex (Solomon et al., 1990; Brewer et al., 2001). Device or machine used contributes 1% of the variability in L* therefore, it is less likely that the difference in L* is a result of the device used (Barkley et al., 2018) rather than muscle fiber type. Carcasses from barrows are often heavier than gilts (Gispert et al., 2010; Lee et al., 2013; Davies et al., 2015), although a few studies have reported no differences (Cisneros et al., 1996; Boler et al., 2014). An increased weight at slaughter is often associated with an increase in the crosssectional area of both oxidative and oxidative-glycolytic fiber types, and L* is moderately correlated (r = 0.40) to the amount of oxidative fiber types (Candek-Potokar et al., 1999). Based on these data, one could surmise that because barrows are heavier than gilts, barrows would produce loins that have a lesser L* than gilts. However, current data from the National Pork Board (2018) suggests that the percent of oxidative fibers does not increase with an increase in carcass weight and there are very few reported differences in L* between barrows and gilts regardless of differences in carcass weight.

A study by Latorre et al. (2003) reported a greater a* value in loins from barrows compared with loins from gilts however, other studies report no differences in a* between the two sexes (Nold et al., 1999; Boler et al., 2014). A difference in a* could be explained by a potential difference in the proportion of fiber types and amount of myoglobin. Myoglobin is more abundant in oxidative fiber types and an increase in the amount of soluble myoglobin is positively correlated (r = 0.23) with a* (Newcom et al., 2004). However, there are no reported differences in the number of oxidative fiber types between barrows and gilts (Solomon et al., 1990; Bee et al., 2004), and no significant correlations between the proportions of oxidative fiber types and a * have been reported (Ozwa et al., 2000; Kim et al., 2013). Regardless of differences in L* and a*, differences in color are not visually discernable to consumers and visual color is not different between loins from barrows and gilts (Correa et al., 2006; Boler et al., 2014).

In addition to instrumental color, muscle fiber type can also have an effect on ultimate pH (Choi et al., 2006). An increase in the proportion of glycolytic fibers decreases pH through rapid glycolysis and accumulation of lactate (Choi et al., 2006). A study by Lowell et al. (2017b) reported a trend ($P$ = 0.06) for a greater early postmortem pH in loins from barrows compared with gilts and that aged loin pH was significantly greater ($P$ = 0.04) in barrows compared with gilts. Loins from barrows and gilts do not differ cook loss and tenderness (Cisneros et al., 1996; Lowell et al., 2017a) and that variability in traits associated with muscling and lean quality, including pH, purge loss, cook loss, and tenderness does not differ between barrows and gilts (Overholt et al., 2016).

**INFLUENCE OF U.S. PORK EXPORT MARKET**

Today, the U.S. exports 2.45 million tons of pork and pork-related products annually [United States Meat Export Federation (USMEF), 2017], which represents approximately 26% of U.S. pork production (National Pork Board, 2017). Mexico and Japan represent two of the top markets for U.S. pork. Mexico imports the most U.S. pork on a total volume basis (801,887 ton; $1.5 billion) while Japan is the largest importer of U.S. pork on a total value basis (393,648 ton; $1.6 billion). Fresh or chilled hams, shoulders, and other bone-in cuts, from the U.S., are almost exclusively exported to Mexico and in 2017, 98.4% of all U.S. exports of fresh and chilled, bone-in hams and shoulders were shipped to Mexico (USDA, 2017). A survey conducted in Mexico, in 2012, identified both color and fat to lean ratio, of fresh pork cuts, as the two most important quality traits consumers use to make purchasing decisions (Ngapo et al., 2017). Out of 486 individuals surveyed, 70% consistently chose the visually lean cuts of meat, when asked to choose between different options of the same fresh cut (Ngapo et al., 2017). Appearance is first evaluated before other characteristics are considered and a fresh appearance is equated with hygienic meat handling (Ngapo et al., 2017). Mexican consumers consider a bright pink, uniform color as an indicator of freshness, and associate a dark color with previously frozen pork (Ngapo et al., 2017). Mexican consumers consider a little fat as important for flavor, but excessive intramuscular fat is generally viewed as unhealthy (Ngapo et al., 2017). Mexican consumers prefer subcutaneous fat to marbling, as it can be trimmed off (Ngapo et al., 2017).

The U.S. is Japan's primary supplier of fresh pork, and pork loins make up 71% of the fresh pork imported from the U.S. into Japan (Oh and See, 2012). Japanese importers rank eating quality as the second most important quality attribute and rank product specifications (marbling and color) as the third most important quality attribute (Murphy et al., 2015). In a survey by Ngapo et al. (2007), 45% of Japanese consumers consistently chose loin chops that were dark in color whereas 28% chose lighter color chops and 27% were inconsistent in their choices. On average, Japanese consumers prefer loin chops with an average NPPC marbling score of 3, but no less than a 2 (Ngapo, 2012). The polarity of these two export markets establishes a need for both lean growth and meat quality production focuses.

**GROWTH AND QUALITY CHARACTERISTICS OF PIETRAIN AND DUROC-SIRED PIGS**

Contrasting demands of a growing export market have required producers to re-evaluate breeding objectives. As a result, pork quality and carcass characteristics are now essential breeding objectives and integrated into many breeding programs in order to meet specific requirements of distinct markets (lean growth vs. meat quality; Miar et al., 2014). Genetic differences for meat quality traits between breeds and genetic variation within breeds make genetic changes in meat quality possible through breed substitution and selection technologies (Cameron et al., 1999). Duroc-based breeds are often used to supply the needs of a quality-focused market (Japan) because of their meat quality advantages whereas Pietrain-sired pigs are commonly used to satisfy the demand for lean pork from Mexico (NPPC, 1995; Schwab et al., 2006).

***Growth and carcass characteristics of Pietrain and Duroc-sired pigs***

There are very few reported differences in growth characteristics between Duroc and Pietrain-sired pigs. One study reports that Duroc-sired pigs had a greater ADFI than Pietrain-sired pigs however, the magnitude of difference between the two was only 0.05 kg ($P < 0.05$), and overall ADG and ending live weight (**ELW**) did not differ between the two populations whether slaughtered at the same age or the same body weight (Blanchard et al., 1999; Latorre et al., 2003). Other studies have reported that Duroc-sired pigs have a greater ELW (Ellis et al., 1996; Edwards et al., 2003). Carcasses from Duroc-sired pigs have a heavier HCW, by approximately 5 kg, and are fatter compared with Pietrain-sired pigs (Edwards et al., 2003). Duroc-sired pigs have a greater back fat thickness and a greater carcass yield compared with Pietrain-sired pigs (Edwards et al., 2003; Latorre et al., 2003). On the other hand, carcasses from Pietrain-sired pigs yield a greater percent of standardized fat-free lean and have a larger loin eye area (Ellis et al., 1996; Edwards et al., 2003). Carcass primal cuts (ham, loin, and Boston butt) from Pietrain-sired pigs make up a greater percent of chilled carcass weight compared with Duroc-sired pigs (Ellis et al., 1996; Edwards et al., 2003).

***Meat quality characteristics***

Duroc-based breeds produce loins that are visually darker and more highly marbled, with a greater ultimate pH (Ellis et al., 1996; Edwards et al., 2003). There are few reported differences in L* and a* of loins from Duroc-sired pigs compared with loins from Pietrain-sired pigs however, a study by Edwards et al. (2003) reported that loins from Duroc-sired pigs had lesser L* values and greater a* values compared with loins from Pietrain-sired pigs. A possible explanation for the difference in these values could be a difference in fiber type and amount of myoglobin. The amount of myoglobin present in muscle is associated with the proportion of oxidative muscle fibers (Joo et. al., 2013). Pietrain-sired pigs have a decreased proportion of oxidative fiber types compared with Duroc-sired pigs, as a result of genetic selection for lean muscle growth (Klont et al., 1998; Chang et al., 2003). This genetic selection for lean growth altered fiber type composition, resulting in a greater proportion of glycolytic fibers and a reduced frequency of oxidative fibers (Klont et al., 1998). An increase in the proportion of glycolytic fiber types has a tendency to increase L* while an increase in the proportion of oxidative fiber types tends to decrease L* and increase a* (Klont et al., 1998; Joo et al., 2013).

Duroc-sired pigs have a greater amount of both intramuscular fat (visual marbling) and extractable lipid compared with Pietrain-sired pigs (Ellis et al., 1996). Increased amounts of intramuscular fat or marbling are often associated with the rate of maturity however, this does not explain the difference in marbling of between loins from Duroc and Pietrain-sired pigs as there is no evidence that Duroc-sired pigs mature at a faster rate than Pietrain-sired pigs. An alternate explanation for this difference could be the difference in proportion of muscle fiber types. Lipids are primarily stored in type I (oxidative) and some type IIA (oxidative-glycolytic) fibers, in the form of triglycerides, and utilized for energy during prolonged exercise or activity (Essen-Gustavsson et al., 1994; Aberle et al., 2001). Oxidative fiber types or “endurance” muscle fibers are associated with prolonged exercise or activity, so it is possible that a greater amount of marbling is reflective of a greater amount of lipid or triglyceride storage (Essen-Gustavsson et al., 1994). Loins from Duroc-sired pigs have a greater ultimate pH compared with Pietrain-sired pigs (Edwards et al., 2003). A shift in fiber type may also explain the difference in pH between loins from Duroc-sired pigs and Pietrain-sired pigs as a greater amount of glycolytic fibers decreases pH through rapid glycolysis and accumulation of lactate (Choi et. al., 2006).

## RELATIONSHIPS BETWEEN EARLY AND AGED POSTMORTEM LOIN QUALITY

Early postmortem quality characteristics and eating experience of pork loins are related and correlations between the two have been established (Huff-Lonergan et al., 2002; Hamilton et al., 2003). Huff-Lonergan et al. (2002) reported that loin pH at 24 h postmortem was weakly correlated to aged L* (r = - 0.32), aged ventral firmness (r = 0.20), cook loss (r = - 0.20), tenderness (r = 0.27), juiciness (r = 0.17), and flavor (r = 0.25). It has also been established that there are correlations between early postmortem loin quality characteristics and aged loin and chop quality characteristics, and these correlations largely do not differ between barrows and gilts (Lowell et al., 2017b). Lowell et al. (2017b) reported that early postmortem (1 d) loin pH was strongly correlated with aged pH (r = 0.80 barrows; 0.75 gilts). Early pH was moderately correlated with aged ventral L* (r = - 0.57 barrows; - 0.54 gilts), aged subjective ventral color (r = 0.55 barrows; 0.41 gilts), and aged subjective chop color (r = 0.42 barrows; 0.44 gilts) (Lowell et al., 2017b). Early ventral L* was moderately correlated with aged ventral L* (r = 0.60 barrows; 0.51 gilts) (Lowell et al., 2017b). Early ventral visual marbling was moderately correlated with aged ventral visual marbling (r = 0.67 barrows; 0.66 gilts) and visual aged chop marbling (r = 0.57 barrows; 0.59 gilts) (Lowell et al., 2017b). There is some indication that marbling (intramuscular fat) is correlated to both sensory and instrumental tenderness (Huff-Lonergan et al., 2002) however, Wilson et al. (2017) reported that extractable lipid explained less than 1% of the variation in sensory tenderness of pork loin chops cooked to a medium-rare degree of doneness (63ºC). Additionally, Rincker et al. (2008) reported that extractable lipid did not influence instrumental or sensory tenderness of pork loins cooked to a medium (71ºC) degree of doneness.

## STATISTICAL ANALYSIS USING CORRELATIONS

Correlation analysis is one of the most widely used and reported statistical methods in summarizing medical and scientific research (Taylor, 1990). This method of analysis is often useful to determine if an association exists between two different variables and if so, how significant or strong the association between the two variables is (Taylor, 1990). The correlation coefficient is often referred to as Pearson's *r* or *r* coefficient, and is the actual value reported that indicates the strength of the association between the two variables in question (Taylor, 1990). The correlation coefficient may range from -1 to 0 to +1, where the values are absolute and unit-less (Taylor, 1990). An *r* coefficient of zero indicates that there is no association between the measured variables however, the closer *r* approaches ±1 the strength of the association between them increases (Taylor, 1990). The stronger the correlation, the better the independent variable (x) predicts the dependent variable (y). A positive linear correlation is when an increase in x corresponds to an increase in y, whereas a negative linear correlation is when an increase in x corresponds to a decrease in y. It is important to remember that strength of the correlation is not dependent on the direction or the sign but rather how far away *r* is from zero (Taylor, 1990). Correlation coefficients can be defined as weak, moderate, and strong. A weak correlation is $r \leq 0.35$, a moderate correlation is $0.36 \leq r \leq 0.67$, and a strong correlation is $r \geq 0.68$ however, a correlation coefficient is not meaningful by itself, but it must be a statistically significant correlation coefficient (Taylor, 1990). In this case, the *P* value is an indication of whether or not the *r* coefficient is statistically different from zero. One complication when interpreting correlation coefficients is the possibility of having a significant correlation that is not necessarily and important one (Taylor, 1990). In populations where the sample size is greater than 100, $r \geq 0.20$ can be significantly different from zero at $P \leq 0.05$ however, while $r = 0.20$ would be considered significant, it only represents 4% of the total variation in the dependent variable that can be explained by the independent variable (Taylor, 1990). Therefore, in large sample sizes (n > 100) it may be useful to calculate the coefficient of determination ($r^2$) as a more conservative measure of the association between the two variables in question (Taylor, 1990). Another caveat of using correlation coefficients is whether or not the confidence interval contains zero. If the confidence interval contains zero, the correlation coefficient is not statistically significant from zero regardless of how close $r$ approaches $\pm 1$ (Tan and Tan, 2010). One limitation or misuse of correlation analysis is the interpretation that correlation equals causation. It is important to remember that correlation analysis measures an association between two variables, but it does not define or explain the basis for the relationship (Taylor, 1990). Another problem with correlation analysis is the potential bias in the estimation of the population correlation (Ott and Longnecker, 2001). The $r$ coefficient is simply a sample correlation that is used as a basis for estimation and significance testing of the population correlation ($\rho$), and there is a potential for bias in the estimation of $\rho$ (Ott and Longnecker, 2001). The choice of x values (independent variables) can increase of decrease the sample correlation; where a wide range of x values can increase the magnitude of the correlation coefficient and a small range of x values can decrease it. Therefore, it is a good idea to consider the residual standard deviation and the magnitude of the slope before deciding how well the linear regression line predicts y (Ott and Longnecker, 2001).

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# Chapter 2

# RELATIONSHIPS AMONG EARLY POSTMORTEM LOIN QUALITY AND AGED LOIN AND PORK CHOP QUALITY CHARACTERISTICS BETWEEN BARROWS AND GILTS

## ABSTRACT

Rapid assessment of pork quality by packers necessitates using early postmortem (~1 d) traits as an indication of aged pork quality (~14 d). Efforts have been made to develop a grading system based on color and marbling of the ventral side of boneless loins. In order for this system to be successful, there must be a correlation between early postmortem quality traits observed by packers and the same traits observed by consumers after aging. However, the strength and direction of those correlations are unclear. It is also unknown if the correlations between early and aged postmortem quality differ between barrows (B) and gilts (G). Therefore, the objectives were to determine correlations between early postmortem loin quality characteristics and aged loin quality characteristics, and determine if those correlations differed between barrows and gilts. Early postmortem (~1 d) quality traits included: instrumental and subjective color, marbling and firmness, and loin pH on the ventral surface of the loin. Loins were aged until 14 d postmortem in vacuum packages. Aged quality traits included traits evaluated early as well as shear force and cook loss. Correlations were compared between barrows and gilts using a Fisher's z test. Overall, early subjective firmness scores of barrows were greater ($P < 0.001$) than those of gilts. No other early quality traits differed between sexes. Early pH was correlated with aged pH (r = 0.80 B; 0.75 G), ventral lightness (r = -0.57 B; -0.54 G), ventral yellowness (r = -0.55 B; -0.55 G), subjective ventral color (r = 0.55, B; 0.41 G), and subjective chop color (r = 0.42 B; 0.44 G). Correlations of early pH and aged quality did not differ between sexes. Early lightness was correlated with aged ventral pH (r = -0.56) and subjective color (r = -0.39) in barrows but not gilts ($P \leq 0.04$). Early lightness was correlated with aged lightness (r = 0.60 B; 0.51 G) and yellowness (r = 0.49 B; 0.55 G), but was not correlated with to any aged chop quality traits. Early marbling was correlated with ventral color (r = 0.42) in barrows and ventral marbling (r = 0.67 B; 0.66 G) and chop marbling (r = 0.57 B; 0.59 G) in barrows and gilts. In summary, early pH and lightness were correlated with aged quality characteristics and correlations rarely differed between barrows and gilts. Sex does not need to be accounted for when relating early and aged quality characteristics.

**Key words:** aged loin quality, correlation, loin quality, pork, quality

## INTRODUCTION

Rapid assessment of pork quality by packers necessitates the use of early postmortem (~ 1 d) traits as an indication of aged pork quality (~ 14 d) and eating experience (Lonergan et al., 2017; Shackelford et al., 2017). Color and marbling are loin quality traits most influential to consumer purchasing decisions (Moeller et al., 2010) and influence the palatability of pork (Huff-Lonergan et al., 2002). The National Pork Board and USDA are developing a grading system based on color and marbling on the ventral side of boneless loins at 1d postmortem (Lusk et al., 2017). For this system to be successful, a strong correlation between early postmortem color and marbling traits observed by packers and the same traits observed by consumers after a period of aging must exist. However, the strengths of those relationships are unclear. Furthermore, the relationships of early and aged quality traits of pork loins may be influenced by other factors including aging environment (temperature, packaging, length of aging) and traits inherent to the pigs or loins themselves (diet, management practices, sex of pigs, pH of loins).

Therefore, before general conclusions can be made about relationships between early and aged quality measurements, the influence of these external factors must be established. In particular, it is imperative to compare these relationships between barrows and gilts, as each represents about half of the pigs slaughtered. Differences in quality traits between barrows and gilts have long been recognized (Martel et al., 1988), and recently variability differences of quality traits were identified between sexes (Overholt et al., 2016). It is possible differences in relationships among early and aged loin quality traits also exists. Therefore, the objectives were to determine correlations between early postmortem loin quality characteristics and aged loin and chop quality characteristics, and determine if those correlations differ between barrows and gilts.

## MATERIALS AND METHODS

### *Pig Background*

Pigs were slaughtered at a federally inspected abattoir under the supervision of the USDA Food Safety and Inspection Service. Loins were obtained from that facility therefore, no Institutional Animal Care and Use Committee approval was needed. Pigs (328 total) were sourced from a single genetic line and were raised under the same commercial conditions. Each pig was tattooed on the ham with a unique number prior to transportation to the abattoir. Pigs were transported approximately 195 km and held in lairage for a minimum of 3 h prior to slaughter. Pigs were immobilized via carbon dioxide gas and terminated by exsanguination. A sequential identification number was written on the shoulder of each carcass with a crayon after evisceration. At the same time, the individual tattoo was recorded so that it could be matched with the sequential number written on the shoulder. Hot carcass weight (**HCW**) was recorded immediately before each carcass entered a blast chiller. Following the approximately 90 min blast-chill, carcasses were transferred to an equilibration cooler, where they remained for approximately 20 h until fabrication. Early and aged loin quality evaluations were collected on 133 barrow carcasses and 195 gilt carcasses slaughtered on 3 different days (d 1 = 103 pigs, d 2 pigs = 168, d 3 = 57 pigs).

***Abattoir Data Collection***

While in the carcass cooler, back-fat thickness was determined by measuring the midline fat thickness at the $10^{th}$ rib. As carcasses moved out of the carcass cooler just prior to fabrication they were weighed again to determine chilled carcass weight. Cooler shrink (%) was calculated using the following equation:

*Cooler shrink (%) = [(HCW, kg – Chilled carcass weight, kg) / HCW, kg] × 100*

Identification buttons (Volk Enterprises, Turlock, CA), corresponding to the sequential identification number written on the shoulder of the carcasses, were placed into Canadian back loins (NAMP #414, NAMI, 2014) after fabrication. Loins were vacuum packaged and placed in boxes. Loins were transported on ice, in coolers, approximately 32 km to the University of Illinois Meat Science Laboratory (Urbana, IL).

***Early Postmortem Pork Quality Evaluation***

Immediately upon arrival to the University of Illinois, boneless loins were removed from the packaging and weighed. Oxygenation of the loins was allowed to occur for at least 20 min before quality evaluations took place. After oxygenation, quality measurements for instrumental lightness (L*), redness (a*), yellowness (b*) (CIE, 1978), subjective color (NPPC, 1999), subjective marbling (NPPC, 1999), subjective firmness (NPPC, 1991), and early postmortem ultimate pH was collected on the ventral surface of the boneless loins by trained University of Illinois personnel. Instrumental color was measured with a Minolta CR-400 Chroma meter

(Minolta Camera Co., Ltd., Osaka, Japan) using a D65 illuminant, an 8 mm aperture, and calibrated using a white tile. Subjective color and marbling scores (NPPC, 1999), and firmness scores (NPPC, 1991) were determined by a single individual. Ultimate pH (~22 -24 h postmortem) was measured using a handheld MPI pH meter fitted with a glass electrode (MPI pH-Meter, Topeka, KS; 2-point calibration; pH 4 and pH 7). After 1d postmortem quality measures were complete, loins were vacuum packaged and aged for 13 d at 4°C.

***Aged Postmortem Pork Quality Evaluation***

***Loin and Chop Quality***

At 14 d postmortem, loins were removed from the packaging, allowed to drip for approximately 20 minutes, and weighed again. Purge loss (%) was calculated using the following equation: *Purge Loss, % = [(1 d weight, kg – 14 d weight, kg) / 1 d weight, kg] ×100*

Loins were exposed to oxygen (fat side against the table and lean side up) for at least 20 min and then quality measurements for instrumental color, subjective color, subjective marbling, subjective firmness, and aged ultimate pH were conducted on the ventral surface of the loins, using the same procedures as the 1 d postmortem quality evaluations. Brewer et al. (2001) reported that time of oxygen exposure from 0 min through 30 min had no effect on instrumental L*. Instrumental a* values did not change after 10 min of oxygen exposure. Thus, 20 min was sufficient to allow for appropriate oxygenation of myoglobin. Ambient room temperature during evaluations was approximately 4°C.

After quality evaluations were completed on the ventral surface of the loins, they were sliced into 2.54 cm thick chops using a push-feed style Treif Puma slicer (Treif model 700 F; Treif, Oberlahr, Germany). Three chops were collected from each loin for further evaluation. The first chop collected was the first chop completely posterior to the spinalis dorsi. Chops 2 and

3 were collected immediately posterior to chop 1. Chops 1 and 3 were exposed to oxygen for at least 20 minutes before evaluation. Then, instrumental lightness (L*), redness (a*), and yellowness (b*) were measured at two locations on the cut surface of both chops 1 and 3 for a total of four instrumental color measurements per experimental unit (loin). The 4 measurements for L*, a*, and b* were then averaged, and the average of the 4 measurements was reported as instrumental color. Subjective color measures (NPPC, 1999) were evaluated on the cut surface of chops 1 and 3, by a single individual, and the average of the 2 subjective color values was reported as subjective color. Chops 1 and 3 were then vacuum packaged and stored at -2°C until they were used to determine cook loss (%) and Warner-Bratzler shear force (**WBSF**). Chop 2 was evaluated for subjective marbling (NPPC, 1999) and then packaged in Whirl-Pak bags (Nasco, Ft. Atkinson, WI) and stored at -2°C until determination of moisture and extractable lipid.

***Cook Loss and Warner-Bratzler Shear Force***

Chops 1 and 3 from each loin were removed from frozen storage at least 24 h prior to analysis and allowed to thaw thoroughly at 4°C. Chops were individually weighed and then cooked on a Farberware Open Hearth grill (model 455N, Walter Kidde, Bronx, NY, USA) on one side to an internal temperature of 34°C, flipped, and then cooked until they reached an internal temperature of 68°C, at which point they were removed from the grill. During cooking, internal temperature was monitored using copper-constantan thermocouples (Type T, Omega Engineering, Stamford, CT, USA) placed in the geometrical center of each chop and connected to a digital scanning thermometer (model 92000-00, Barnat Co, Barrington, IL). Chops were cooled to approximately 25°C, and weighed again to determine cook loss percentage. Three 1.25 cm diameter cores from each chop were removed parallel to the orientation of the muscle fibers and sheared using a Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, NY/Stable Mirosystems, Godalming, UK) with a blade speed of 3.33 mm/s and a load cell capacity of 100 kg. Warner-Bratzler shear force values from 3 cores from chop 1 and 3 cores from chop 3, for a total of 6 cores, were averaged to determine a single WBSF value for each experimental unit (loin).

***Proximate Composition***

Chops stored for moisture and extractable lipid determination were allowed to partially thaw at 25° C, taking care to prevent loss of exudate. Chops were prepared for evaluation by trimming all subcutaneous fat and secondary muscles before homogenizing in a Cuisinart (East Windsor, NJ) food processor. Any exudate from the package was added to the meat prior to homogenization. Samples were blended for approximately 90 seconds in the mixer until they were visually homogenized. Moisture was determined by drying duplicate 10 g samples from each loin chop in a drying oven set to 110°C for at least 24 h. Extractable lipid content was determined using the chloroform-methanol solvent method described by Novakofski et al. (1989).

***Statistical Analyses***

Because early and late quality evaluations were compared within a loin from the same pig, pig served as the experimental unit for all statistical analyses. Carcass and loin quality characteristics from barrows and gilts were compared using a one-way ANOVA in the MIXED procedure of SAS 9.4 (SAS Inst. In., Cary, NC). The model included the fixed effect of sex and the random effect of slaughter date. Differences in quality traits between barrow and gilts were considered different at $P \leq 0.05$.

Comparisons of independent correlation coefficients between barrows and gilts were achieved following the example of Kenny (1987) using a z-test for comparing 2 independent correlations. First, data were grouped into two individual data sets by sex (barrows and gilts). For each of these two datasets, Pearson correlation coefficients were calculated and transformed using the Fisher's r to z transformation with the FISHER option of the CORR procedure in SAS. The Fisher's r to z transformation was defined as:

$$z = \frac{1}{2} ln \left[\frac{1 + r}{1 - r}\right]$$

and used to ensure the transformed coefficients were nearly normally distributed and to make the variance of correlations approximately the same regardless of the value of the population correlation (Kenny, 1987). Where *r* is the Pearson correlation coefficient and *z* is the transformed value of the correlation coefficient. If the *z* value is statistically significant, then the correlations between the two populations (barrows and gilts) differ (Kenny, 1987). Correlations were considered weak (in absolute value) at $r < 0.35$, correlations were considered moderate at $0.36 \geq r < 0.67$, and strong correlations were those $r \geq 0.68$ (Taylor, 1990). Next, Fisher's transformed z values were merged into a single data set and compared using the equation:

$$z = \frac{z_{barrows} - z_{gilts}}{\sqrt{\frac{1}{n_{barrows} - 3} + \frac{1}{n_{gilts} - 3}}}$$

Taylor et al. (1990) cautions that correlation coefficients of 0.20 in data sets with more than 100 observations, like in this data set, can be statistically different from 0 ($\alpha = 0.05$), but have little practical importance. Therefore, differences in relationships of early and aged postmortem loin quality between barrows and gilts were considered different at $P \leq 0.05$ but must have had a correlation coefficient of $|r| \geq 0.36$ to be discussed as practically relevant.

Correlation coefficients differed between barrows and gilts on 4 occasions. In each of those occasions, independent slopes for barrows and gilts were compared using the REG procedure in SAS by independently calculating the slopes and mean squared error of each sex. Then using and the standard error of the difference between the two slopes, slopes were compared to confirm differences in relationships between barrows and gilts.

## RESULTS

### *Difference Between Barrows and Gilts for Early and Late Postmortem Quality Characteristics*

Mean differences between barrows and gilts were expected. Barrows were heavier and fatter than gilts ($P \leq 0.01$, **Table 2.1**), but had loins that were lighter as a percentage of HCW ($P \leq 0.0001$). Early postmortem loin subjective firmness was greater ($P \leq 0.001$) for loins from barrows compared with those from gilts (**Table 2.1**). There were no differences ($P \geq 0.06$) for any other early postmortem loin quality traits between barrows and gilts. Aged ventral subjective marbling ($P = 0.02$), ultimate pH ($P = 0.04$), and percent purge ($P \leq 0.01$) were greater in loins from barrows compared with loins from gilts (**Table 2.2**). There were no differences ($P \geq 0.35$) for any other aged ventral loin quality traits between barrows and gilts. Aged loin chop subjective color ($P = 0.04$), subjective marbling ($P \leq 0.0001$), and extractable lipid percentage ($P \leq 0.01$) was greater in loin chops from barrows compared with loin chops from gilts. Moisture percentage was less ($P = 0.04$) in chops from barrows compared with chops from gilts. There were no differences in any other aged loin chop quality characteristics between barrows and gilts.

### *Comparison of Barrow and Gilt Correlation Coefficients Between Early Postmortem and Aged Quality Traits*

Kenny (1987) cautions that it is inappropriate to conclude correlations statistically differ between two treatment groups when the independent correlation of one treatment group is different from zero and the other independent correlation may or not be different from zero. One must explicitly test whether the two correlations differ and not rely on the significance tests of the correlations calculated individually (Kenny, 1987). One caveat with the interpretation of a correlation is that it does not provide any information as to why relationships may differ between barrows and gilts. Early loin pH was correlated with aged pH (r = 0.80 barrows; 0.75 gilts), ventral lightness (r = -0.57 barrows; -0.54 gilts), ventral yellowness (r = -0.55 barrows; -0.55 gilts), subjective ventral color (r = 0.55, barrows; 0.41 gilts), and subjective chop color (r = 0.42 barrows; 0.44 gilts) (**Table 2.3**). Early loin pH was not related to ventral redness, ventral marbling, ventral firmness, chop lightness, chop redness, chop yellowness, or chop marbling (**Table 2.3**). Correlation coefficients with early pH and aged quality traits did not differ between barrows and gilts for any quality trait (**Table 2.3**).

***Early Postmortem Ventral Instrumental Lightness (L*)***

Early lightness was correlated with aged ventral pH (r = -0.56) and subjective color (r = -0.39) in barrows but not gilts ($P \leq 0.04$) (**Table 2.4**). Early lightness was correlated with aged lightness (r = 0.60 barrows; 0.51 gilts) and yellowness (r = 0.49 barrows; r = 0.55 gilts) in both barrows and gilts. Early ventral lightness was not correlated to aged ventral redness, subjective marbling, or firmness, nor was it correlated with any instrumental or subjective color trait on the chop face. Early ventral lightness was also not correlated with chop marbling (**Table 2.4**). Correlation coefficients did not differ for early instrumental lightness and aged quality traits between barrows and gilts except for aged pH (**Fig. 2.1**). Even so, independent slopes of prediction lines between barrows ($\beta_1$ = -0.016) and gilts ($\beta_1$ = -0.008) for instrumental lightness and aged pH did not differ ($P$ = 0.10). On the other hand, independent slopes of prediction lines between barrows ($\beta_1$ = -0.067) and gilts ($\beta_1$ = -0.010) for early instrumental lightness and subjective color were different ($P$ = 0.02, **Fig. 2.2**).

***Early Postmortem Ventral Instrumental Redness (a*) and Yellowness (b*)***

Early redness was correlated with ventral color (r = 0.44 barrows; 0.51 gilts) and chop color (r = 0.62 barrows; 0.41 gilts) in barrows and gilts and ventral firmness (r = 0.39) in barrows (Table 5). However, correlation coefficients of early redness and aged quality traits did not differ between barrows and gilts for any quality trait (**Table 2.5**).

Early instrumental yellowness was correlated with ventral color (r = -0.61) and chop color (r = -0.51) in barrows and aged ventral pH (r = -0.47 barrows; -0.60 gilts) in barrows and gilts (**Table 2.6**). Correlation coefficients with early yellowness and aged quality traits did not differ between barrows and gilts for any quality trait (**Table 2.6**).

***Early Postmortem Ventral Subjective Color***

Early subjective color was not correlated with any aged quality traits (**Table 2.7**). The correlation coefficients between early subjective color and ventral redness differed ($P$ = 0.04) between barrows and gilts where the correlations in barrows was different from 0 (95% CI range = 0.11 to 0.43) but was not different from 0 in gilts (95% CI range = -0.10 to 0.19). This was supported by independent slopes of prediction lines between barrows ($\beta_1$ = 0.516) and gilts ($\beta_1$ = 0.085) for early postmortem ventral subjective color and aged ventral instrumental redness values were different ($P$ = 0.04, **Fig. 2.3**).

***Early Postmortem Ventral Subjective Marbling***

Early subjective marbling was correlated with aged ventral marbling (r = 0.67 barrows; r = 0.66 gilts) and chop marbling (r = 0.57 barrows; 0.59 gilts) in barrows and gilts and aged ventral color (r = 0.42) and aged chop color (r = 0.37) in barrows (**Table 2.8**). Correlation coefficients of early marbling and aged quality traits did not differ between barrows and gilts for any quality trait (**Table 2.8**).

***Early Postmortem Quality Traits and Warner-Bratzler Shear Force and Cook Loss***

No early postmortem quality traits were correlated with WBSF or cook loss in barrows (**Table 2.9**). Early loin pH (r = -0.41) and ventral yellowness (r = 0.45) were correlated with cook loss in gilts. The correlation coefficients between early postmortem ventral firmness and WBSF differed ($P$ = 0.04) between barrows and gilts (**Table 2.9**). Ventral firmness was weakly (r = 0.18) but positively correlated with WBSF in barrows (**Table 2.9**). Ventral firmness was weakly (r = -0.21) but inversely correlated with WBSF in gilts. This is supported by independent slopes of prediction lines between barrows ($\beta_1$ = 0.112) and gilts ($\beta_1$ = -0.039) for early postmortem ventral subjective firmness and WBSF values were different ($P$ = 0.04, **Fig. 2.4**).

**DISCUSSION**

While both packers and consumers use similar traits to assess the quality of pork loins, the surface they assess and the time postmortem when they make those assessments are different. Packers assess loin quality based on color and marbling on the ventral surface of loins during carcass fabrication at 1d postmortem (King et al., 2011). At this time, darker loins with more marbling are often selected for premium-based programs (Holmer and Sutton, 2009, Lusk et al., 2017). In contrast, consumers assess color (Mancini and Hunt, 2005) and sometimes marbling on the surface of loin chops at the time of purchase (Moeller et al., 2010). Consumers discriminate against chops that are too light or too dark, or are discolored. Consumers then determine eating quality, and therefore, repeat purchase intent, on tenderness and juiciness of cooked loin chops. There has been some indication that marbling positively affects tenderness and juiciness. Pork chops with increased marbling have been perceived by consumers and trained sensory panelists to be juicier and more tender (Lonergan et al., 2007), but results appeared to be more pH dependent than marbling dependent. Others have reported no influence of marbling on tenderness and juiciness even over large ranges in marbling scores (Rincker et al., 2008, Wilson et al., 2017). The ultimate goal of packer selection of "high quality" loins is to increase consumer satisfaction and therefore increase consumer purchases of product. Therefore, early postmortem quality characteristics and eating experience must be related. Indeed, these correlation coefficients have been previously established (Huff-Lonergan et al., 2002) However, the relationship between early postmortem characteristics observed on the ventral side of loins and the same traits measured after aging on either the ventral side of loins or the face of chops from those loins has not been well established. Thus, one objective of this work was to determine correlations between early postmortem loin quality characteristics and aged loin and chop quality characteristics.

Packers in the U.S. have historically monitored loin pH as an indication of loin quality. Loin pH is correlated with other pork quality traits such as water holding capacity, color, and firmness (Huff-Lonergan et al., 2002; Boler et al., 2010) In the present study, loin pH at 1 d postmortem was moderately correlated to aged ventral loin color and aged loin chop color. This is supported by previous research (Huff-Lonergan et al., 2002) which also observed that ultimate loin pH was weakly correlated with aged loin color. However, the study by Huff-Lonergan et al. (2002) only aged loins for 2 d postmortem and therefore, may not be truly representative of the quality traits observed by the consumer. Another study, by Hamilton et al. (2003), also reported a relationship between pH and L* however, similar to the study by Huff-Lonergan et al. (2002)

quality measurements were measured at approximately 2 d postmortem and most likely does not reflect the traits consumers will observe.

The correlation between early color with aged color is also supported by a relationship between early ventral a* and both aged ventral subjective color and aged chop subjective color. Huff-Lonergan et al. (2002) observed a strong correlation between early postmortem (2 d) L* and early postmortem (2 d) color. However, Huff-Lonergan et al. (2002) determined that correlations did not exist between early L* and aged color, so it is possible that over time, those correlations would become weaker. During aging, proteolysis can alter water holding capacity and color, therefore, quality traits may change with postmortem aging (Hwang et al., 2005). Ultimately, the goal of selecting loins based on quality characteristics in the early postmortem period is to segregate loins based on expected eating quality. Tenderness is often cited as the most important quality trait for consumer eating experience (Moeller et al., 2010). Thus, the correlation coefficient between early postmortem quality characteristics observable by packers and tenderness is important. While WBSF was weakly correlated with early pH and early L*, the majority of early postmortem quality traits did not correlate to aged tenderness in the present study. Previous work reported weak correlations between aged tenderness and early postmortem traits, such as marbling, but aged tenderness was not correlated with ultimate pH or color (Dilger et al., 2010) similar to the present study. Marbling is thought to be an important trait for pork tenderness. Moderate correlations between early ventral marbling and aged ventral marbling, early ventral marbling and aged chop marbling, and aged ventral marbling and aged chop marbling indicate that estimates of marbling on the ventral surface at early times postmortem are valid. But early ventral marbling estimates were not correlated with WBSF in either barrows or gilts. Rincker et al. (2008) reported that extractable lipid (range 0.76% to 8.09%) did not influence instrumental or sensory tenderness of pork loins cooked to a medium (71°C) degree of doneness. Likewise, Wilson et al., (2017) reported that extractable lipid (range 0.80% to 5.52%) explained less than 1% of the variation in sensory tenderness of pork loins cooked to a medium-rare degree of doneness (63°C).

Pork carcasses, unlike beef carcasses, are not routinely ribbed (cut between the 10$^{th}$ and 11$^{th}$ rib to expose the longissimus muscle) in the United States. Therefore, estimations of quality by packers is done on the ventral surface of a boneless loin after carcass fabrication. Consumers most often observe the cut surface of loin chops. However, most observations made on the ventral surface of both early and aged loins were not correlated with the corresponding observations made on the chop face of aged loin chops. Subjective chop color was the lone exception. This indicates that estimates of ventral quality, both early and aged, are not necessarily indicative of aged chop quality. The lack of correlation between ventral and chop measurements is troubling because it suggests that what is observed at the processing facility is not what is observed by consumers. That is potentially the result of variation within a loin (Van Oeckel and Warnants, 2003), but also that perception of color may be influenced by the direction of the muscle fibers during observation. When color was assessed on the ventral side of loins, the muscle fibers were oriented mostly perpendicular to the observer. In other words, the observer was viewing muscle fiber longitudinally. But when observed on the chop face, the cross-section of muscle fibers was visible to observers. This difference in fiber directionality could alter the perception of color between these two locations.

Compositional differences between barrows and gilts are well known and, in the current study, were similar to previous research (Friesen et al., 1994; Cisneros et al., 1996). Barrows had greater ending live weights than gilts with more back fat and greater extractable lipid, but gilts produced heavier Canadian back loins yielded a greater percent of estimated carcass lean compared to barrows (Friesen et al., 1994). Bruner et al. (1958) and Hale and Southwell (1967) also observed that barrows were heavier than gilts, but gilts were leaner, had a greater carcass yield, less backfat, and larger loin eye area. A more recent study by Cisneros et al. (1996) confirmed these differences between barrows and gilts, similar to the present study. There were minimal differences between barrows and gilts in regard to fresh meat quality. Loins from gilts were more firm than loins from barrows, had greater cooking loss, but did not differ in WBSF. Increased firmness in loins from gilts may be related to increased WHC, as demonstrated by DeVol et al. (1988). Previous reports have also failed to detect differences in tenderness between barrows and gilts (Cisneros et al., 1996; Latorre et al., 2004). Therefore, while sex does not affect tenderness, it may affect WHC and cooking loss.

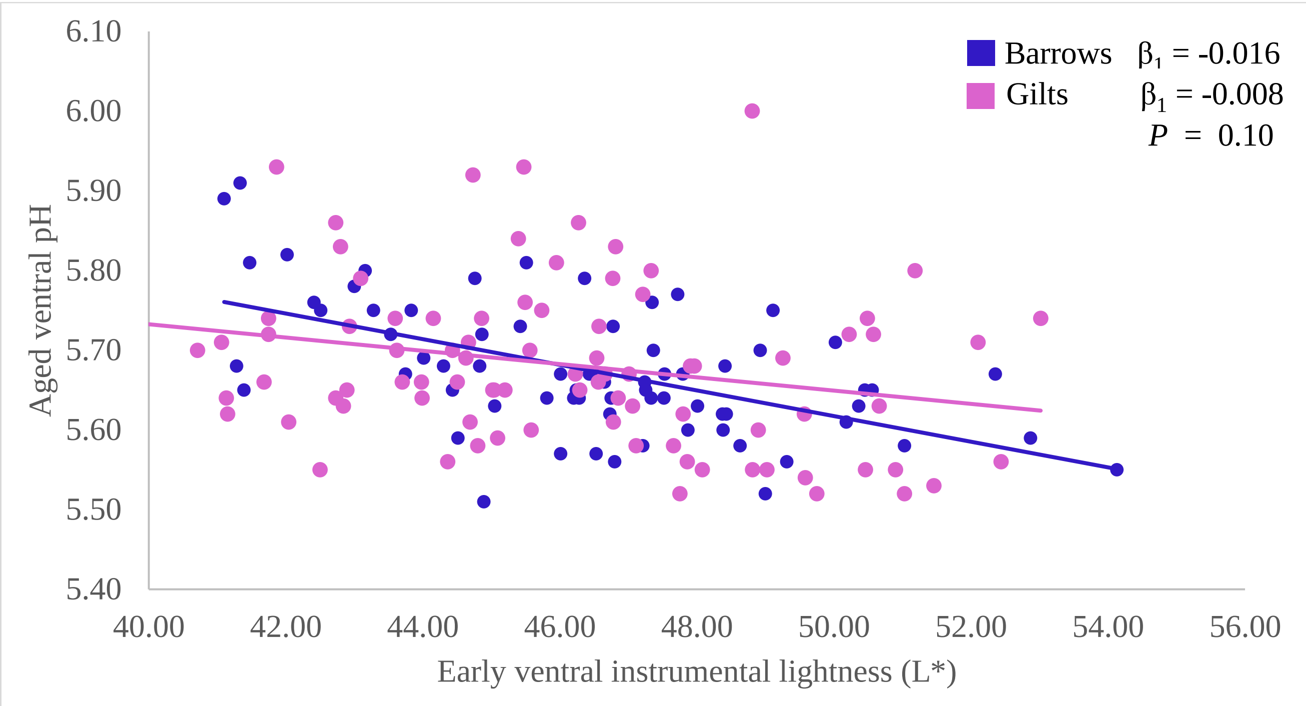
It is not common at either commercial farms or slaughter facilities to segregate barrows and gilts. Therefore, when packers make assessments of quality, sex is not known. Because barrows and gilts differ in both the mean and variability of some quality and composition traits (Overholt et al., 2016), the hypothesis was that the relationships among early and aged quality characteristics may differ between barrows and gilts. Therefore, the second objective of this study was to determine if correlations between early postmortem loin quality characteristics and aged loin and chop quality characteristics differed between barrows and gilts.

In general, correlation coefficients between early and aged postmortem quality did not differ between barrows and gilts. However, there were 4 early postmortem quality characteristics that were correlated differently to aged quality traits between the 2 sexes. It is important to determine if these differences are significant and if sex should be accounted for when using early postmortem quality traits to predict aged quality. To that point, the independent slopes for both barrows and gilts were negative (as became lighter, pH was less) between early postmortem ventral lightness and aged ventral pH, but the correlation in barrows was moderately strong in barrows, but weak in gilts. Likewise, there was a moderately strong inverse correlation and a negative slope in barrows between early ventral lightness and aged ventral color (as loins became lighter instrumentally, they also became lighter visually), but no predictive ability of aged ventral color using early instrumental lightness in gilts. Early subjective color was positively, yet weakly, correlated with aged ventral redness in barrows, but subjective color score was not related to aged redness scores in gilts. This indicates no predictive ability of aged redness scores in gilts and poor predictive ability of aged redness scores in barrows using early ventral color. Finally, early ventral firmness was not predictive of WBSF for either barrows or gilts, but the directionality of the correlations differed between barrows and gilts. This inconsistency between barrows and gilts was anticipated. Arkfeld et al. (2015) reported weak or no correlation between firmness and other meat quality traits. Overholt et al. (2016) reported greater variability in early subjective color scores of loins from gilts compared with loins from barrows. In most cases variability (a greater range) in the trait of interest increases the likelihood of a relationship being detected. However, if subjective color of gilts is more variable than subjective color of barrows and that variability is different from early and aged color, it is possible this explains the differences in the correlation coefficients of color scores between barrows and gilts with other quality traits.

Based on the results of the present study it may be possible to use early pH, L*, and a* as indicators of aged color. Additionally, early pH and L* may provide limited information regarding tenderness, but those correlations were weak. It should also be noted that while early ventral quality may be used to estimate aged ventral quality, data from this study suggest that early and aged ventral loin color may not be accurate estimators of aged chop color. Additionally, while there are differences between barrows and gilts in terms of quality characteristics, the relationship between early and aged quality did not differ between barrows and gilts. Thus, sex does not need to be accounted for when using early postmortem quality traits to predict aged quality.

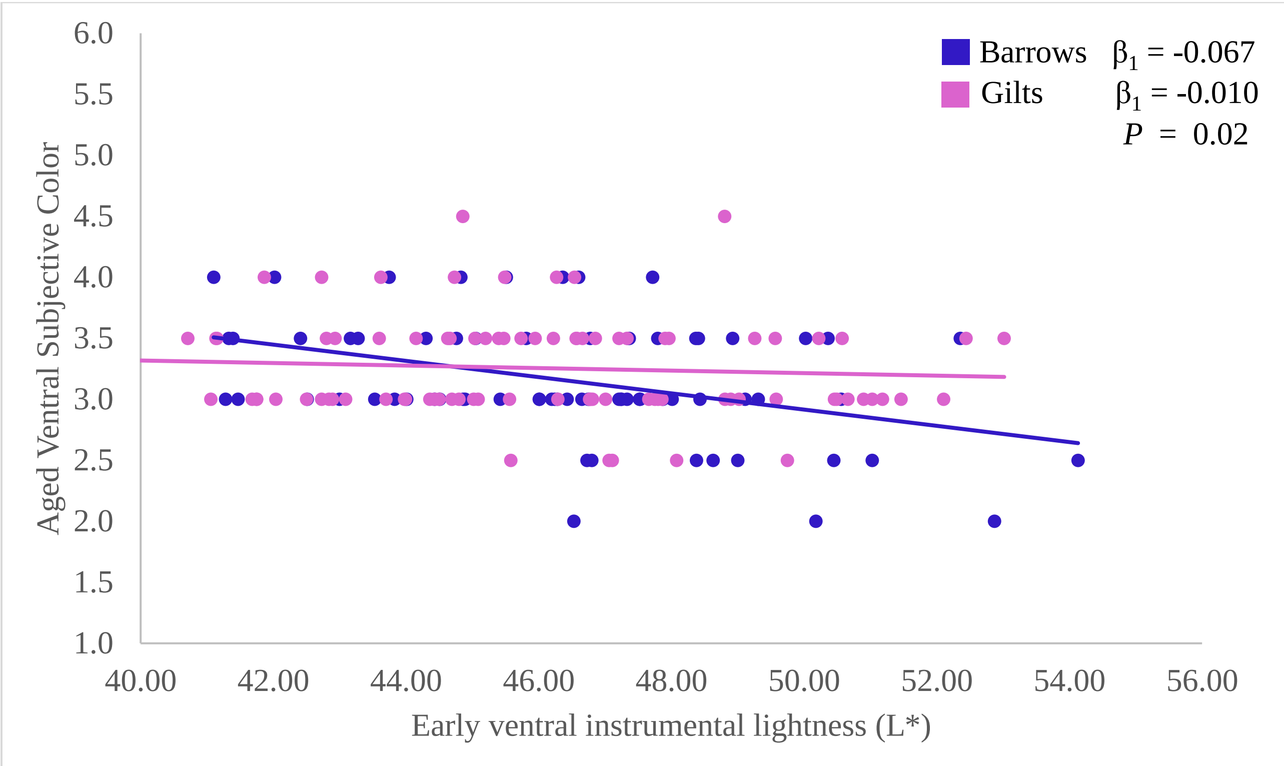
## TABLES AND FIGURES

**Figure 2.1**



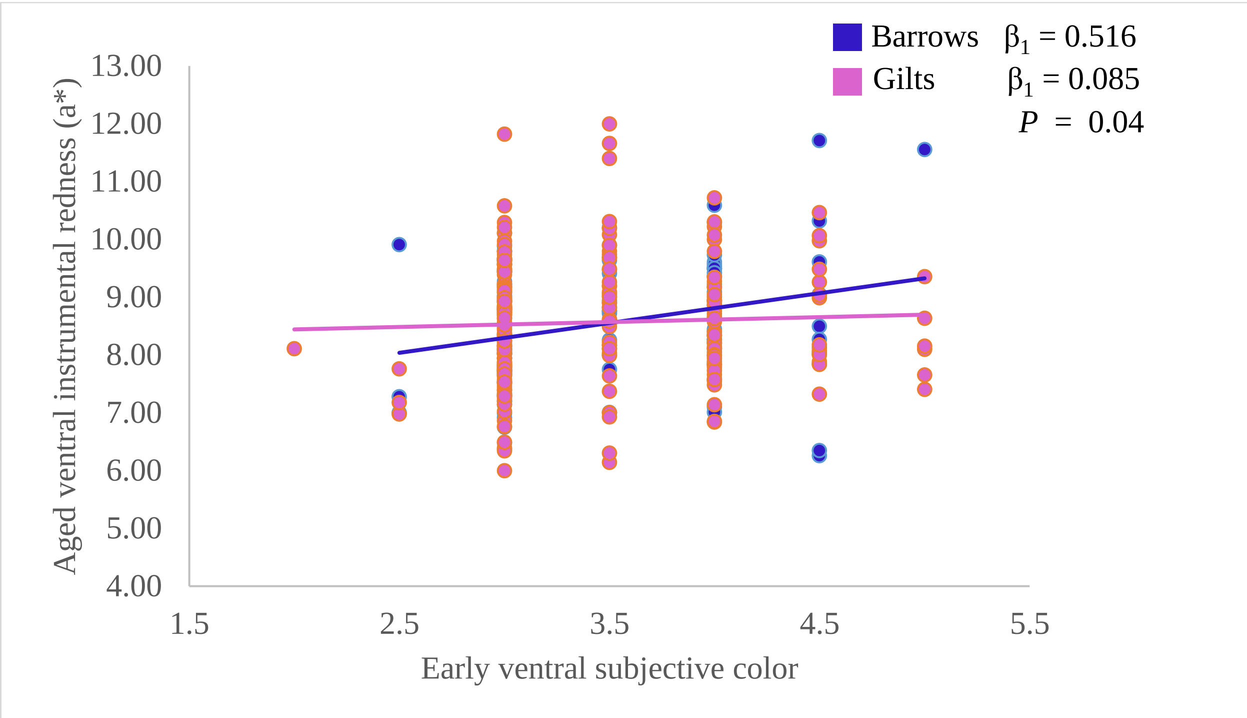

Differences correlation coefficients between early postmortem (1 d) ventral instrumental lightness (L*) and aged (14 d) loin pH of barrows and gilts. Probability values compare slopes ($\beta_1$) of the regression lines between barrows and gilts.

**Figure 2.2**



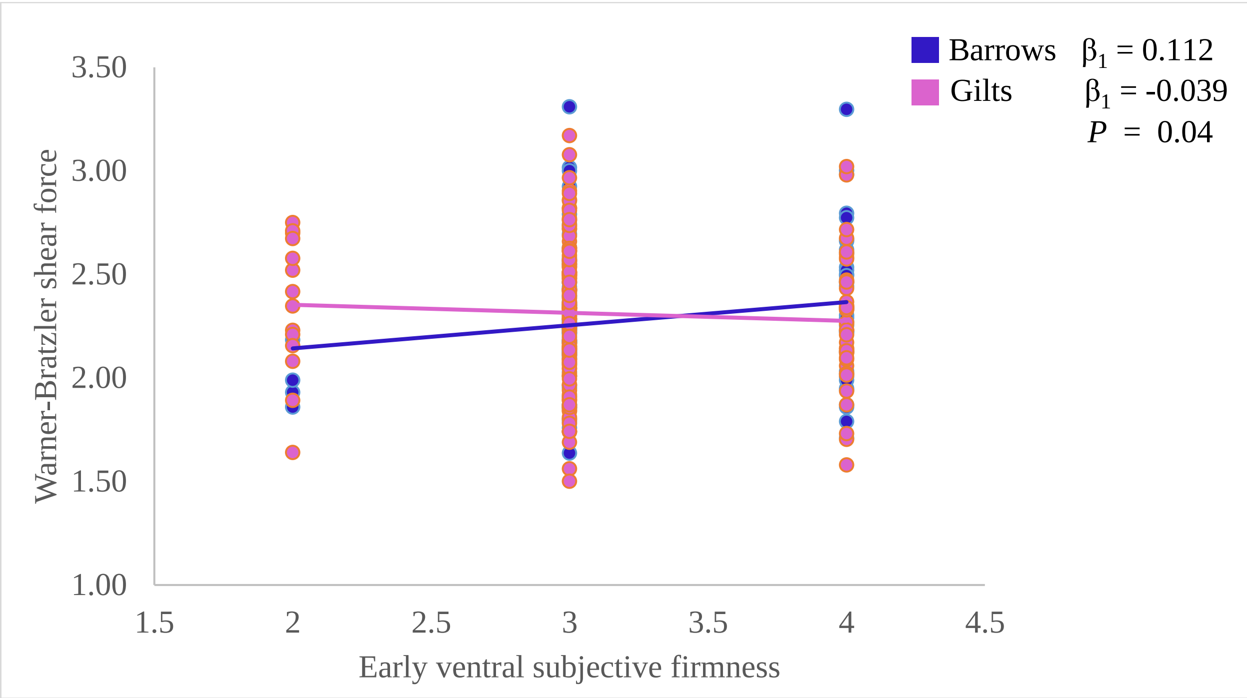

Differences in correlation coefficients between early postmortem (1 d) ventral instrumental lightness (L*) and aged (14 d) ventral subjective color scores of barrows and gilts. Probability values compare slopes ($\beta_1$) of the regression lines between barrows and gilts.

**Figure 2.3**




Differences correlation coefficients between early postmortem (1 d) subjective color scores and aged (14 d) ventral instrumental redness (a*) of barrows and gilts. Probability values compare slopes ($\beta_1$) of the regression lines between barrows and gilts.

**Figure 2.4**




Differences in correlation coefficients between early postmortem (1 d) ventral subjective firmness scores and aged (14 d) Warner-Bratzler shear force values of barrows and gilts. Probability values compare slopes ($\beta_1$) of the regression lines between barrows and gilts.

**Table 2.1.** Carcass characteristics and early postmortem meat quality traits of barrows and gilts collected on the ventral side of the longissimus muscle

| Item | Sex | | SEM | *P* - Value |
|---|---|---|---|---|
| | Barrows | Gilts | | |
| Pigs, n | 133 | 195 | | |
| Carcass characteristics | | | | |
| Ending live wt, kg | 133.54 | 131.42 | 1.55 | 0.01 |
| Hot carcass wt, kg | 101.88 | 100.58 | 1.03 | 0.06 |
| Carcass yield, % | 76.22 | 76.53 | 1.06 | 0.30 |
| Chilled carcass wt, kg | 100.25 | 99.00 | 1.07 | 0.07 |
| Cooler shrink[1], % | 1.48 | 1.52 | 0.15 | 0.84 |
| Last rib midline fat thickness, cm | 2.88 | 2.59 | 0.16 | < 0.0001 |
| Canadian back loin (NAMP #414) wt, kg | 3.62 | 3.85 | 0.07 | < 0.0001 |
| % chilled carcass wt | 7.23 | 7.79 | 0.08 | < 0.0001 |
| Early postmortem ventral quality traits | | | | |
| Instrumental color[2] | | | | |
| Lightness, L* | 46.91 | 46.09 | 0.94 | 0.09 |
| Redness, a* | 8.88 | 8.90 | 0.78 | 0.92 |
| Yellowness, b* | 0.41 | 0.09 | 0.70 | 0.06 |
| Subjective evaluations | | | | |
| Color score | 3.61 | 3.67 | 0.34 | 0.15 |
| Marbling score | 2.46 | 2.32 | 0.17 | 0.06 |
| Firmness score | 3.40 | 3.19 | 0.20 | < 0.001 |
| Loin pH[3] | 5.62 | 5.59 | 0.02 | 0.06 |

[1]Cooler shrink = [(HCW - chilled carcass wt,) / HCW] × 100

[2]L* measures darkness to lightness (greater L* indicates a lighter color), a* measures redness (greater a* indicates a redder color), b* measures yellowness (greater b* indicates a more yellow color)

[3]Loin pH was measured on the ventral surface of the boneless loins at the area of the 10th rib

**Table 2.2.** Aged postmortem (14 d) meat quality traits of barrows and gilts collected on the ventral side or chop face of the longissimus muscle

| | Sex | | | |
|---|---|---|---|---|
| Item | Barrows | Gilts | SEM | *P* – value |
| Pigs, n | 133 | 195 | | |
| *Ventral* | | | | |
| Instrumental color[1] | | | | |
| Lightness, L* | 50.29 | 50.01 | 0.26 | 0.41 |
| Redness, a* | 8.48 | 8.59 | 0.16 | 0.41 |
| Yellowness, b* | 3.25 | 3.18 | 0.21 | 0.64 |
| Subjective evaluations | | | | |
| Color score | 3.39 | 3.38 | 0.19 | 0.80 |
| Marbling score | 2.57 | 2.40 | 0.22 | 0.02 |
| Firmness score | 3.24 | 3.29 | 0.17 | 0.35 |
| Ultimate pH | 5.72 | 5.70 | 0.03 | 0.04 |
| Purge loss[2], % | 4.11 | 3.35 | 0.62 | < 0.01 |
| *Chop* | | | | |
| Instrumental color[1] | | | | |
| Lightness, L* | 51.28 | 51.02 | 0.37 | 0.32 |
| Redness, a* | 8.86 | 8.89 | 0.22 | 0.74 |
| Yellowness, b* | 4.10 | 3.98 | 0.15 | 0.26 |
| Subjective evaluations | | | | |
| Color score | 3.53 | 3.45 | 0.24 | 0.04 |
| Marbling score | 2.55 | 2.16 | 0.26 | < 0.0001 |
| Moisture, % | 73.91 | 74.17 | 0.31 | 0.04 |
| Extractable lipid, % | 2.71 | 2.31 | 0.20 | < 0.01 |
| Warner-Bratzler shear force, kg | 2.27 | 2.29 | 0.05 | 0.49 |
| Cook loss, % | 19.31 | 19.20 | 0.83 | 0.66 |

[1]L* measures darkness to lightness (greater L* indicates a lighter color), a* measures redness (greater a* indicates a redder color), b* measures yellowness (greater b* indicates a more yellow color).
[2]Purge loss = [(1 d weight, kg – 14 d weight, kg) / 1 d weight, kg] ×100

**Table 2.3.** Comparison of Fisher's r to z transformed correlation coefficients comparisons (rho) of early postmortem loin pH values with aged loin quality and chop quality of barrows and gilts[1,2]

| | Barrow pH | | | Gilt pH | | | |
|---|---|---|---|---|---|---|---|
| | | 95% Confidence limit | | | 95% Confidence limit | | |
| Aged postmortem variable | Rho | Lower | Upper | Rho | Lower | Upper | *P* - value[3] |
| *Loin* | | | | | | | |
| Loin pH | 0.80 | 0.72 | 0.85 | 0.75 | 0.69 | 0.81 | 0.38 |
| Ventral lightness, L* | -0.57 | -0.68 | -0.44 | -0.54 | -0.63 | -0.43 | 0.67 |
| Ventral redness, a* | -0.23 | -0.39 | -0.06 | -0.28 | -0.41 | -0.14 | 0.65 |
| Ventral yellowness, b* | -0.55 | -0.66 | -0.41 | -0.55 | -0.64 | -0.44 | 0.96 |
| Ventral color | 0.55 | 0.41 | 0.66 | 0.41 | 0.28 | 0.52 | 0.11 |
| Ventral marbling | 0.29 | 0.12 | 0.45 | 0.30 | 0.16 | 0.42 | 0.99 |
| Ventral firmness | 0.11 | -0.06 | 0.28 | 0.06 | -0.09 | 0.20 | 0.62 |
| *Chop* | | | | | | | |
| Lightness, L* | 0.10 | -0.09 | 0.27 | 0.08 | -0.07 | 0.22 | 0.88 |
| Redness, a* | 0.16 | -0.02 | 0.33 | 0.09 | -0.06 | 0.23 | 0.53 |
| Yellowness, b* | 0.12 | -0.06 | 0.30 | 0.12 | -0.03 | 0.26 | 0.97 |
| Color | 0.42 | 0.26 | 0.56 | 0.44 | 0.31 | 0.55 | 0.88 |
| Marbling | 0.17 | -0.01 | 0.34 | 0.31 | 0.17 | 0.44 | 0.19 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]Aged postmortem traits were evaluated 14 d postmortem

[3]Probablity value comparing correlation coefficients of meat quality traits between barrows and gilts

**Table 2.4.** Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem instrumental lightness (L*) values with aged loin quality and chop quality of barrows and gilts[1,2]

| | Barrow L* | | | Gilt L* | | | |
|---|---|---|---|---|---|---|---|
| | | 95% Confidence limit | | | 95% Confidence limit | | |
| Aged postmortem variable | Rho | Lower | Upper | Rho | Lower | Upper | *P* - value[3] |
| *Loin* | | | | | | | |
| Loin pH | -0.56 | -0.70 | -0.37 | -0.25 | -0.44 | -0.05 | 0.02 |
| Ventral lightness, L* | 0.60 | 0.42 | 0.73 | 0.51 | 0.33 | 0.65 | 0.43 |
| Ventral redness, a* | -0.25 | -0.46 | -0.02 | -0.01 | -0.22 | 0.20 | 0.13 |
| Ventral yellowness, b* | 0.49 | 0.29 | 0.65 | 0.55 | 0.39 | 0.68 | 0.59 |
| Ventral color | -0.39 | -0.57 | -0.17 | -0.08 | -0.28 | 0.13 | 0.04 |
| Ventral marbling | -0.06 | -0.29 | 0.18 | 0.14 | -0.08 | 0.34 | 0.22 |
| Ventral firmness | -0.02 | -0.25 | 0.21 | 0.24 | 0.03 | 0.43 | 0.10 |
| *Chop* | | | | | | | |
| Lightness, L* | 0.03 | -0.21 | 0.26 | 0.06 | -0.15 | 0.27 | 0.84 |
| Redness, a* | 0.04 | -0.20 | 0.27 | -0.03 | -0.24 | 0.18 | 0.66 |
| Yellowness, b* | 0.07 | -0.17 | 0.30 | -0.04 | -0.25 | 0.17 | 0.49 |
| Color | -0.24 | -0.45 | -0.01 | 0.05 | -0.16 | 0.26 | 0.07 |
| Marbling | 0.24 | 0.00 | 0.45 | 0.13 | -0.08 | 0.33 | 0.49 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]Aged postmortem traits were evaluated 14 d postmortem

[3]Probablity value comparing correlation coefficients of meat quality traits between barrows and gilts

**Table 2.5.** Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem instrumental redness (a*) values with aged loin quality and chop quality of barrows and gilts[1,2]

| | Barrow a* | | | Gilt a* | | | |
|---|---|---|---|---|---|---|---|
| | | 95% Confidence limit | | | 95% Confidence limit | | |
| Aged postmortem variable | Rho | Lower | Upper | Rho | Lower | Upper | *P* - value[3] |
| *Loin* | | | | | | | |
| Loin pH | 0.03 | -0.21 | 0.26 | 0.19 | -0.02 | 0.39 | 0.31 |
| Ventral lightness, L* | -0.14 | -0.36 | 0.10 | -0.06 | -0.27 | 0.15 | 0.64 |
| Ventral redness, a* | 0.17 | -0.07 | 0.39 | 0.18 | -0.03 | 0.38 | 0.92 |
| Ventral yellowness, b* | 0.18 | -0.06 | 0.40 | 0.26 | 0.05 | 0.45 | 0.61 |
| Ventral color | 0.44 | 0.22 | 0.61 | 0.51 | 0.34 | 0.65 | 0.56 |
| Ventral marbling | 0.22 | -0.01 | 0.44 | 0.34 | 0.15 | 0.52 | 0.42 |
| Ventral firmness | 0.39 | 0.17 | 0.57 | 0.29 | 0.08 | 0.47 | 0.50 |
| *Chop* | | | | | | | |
| Lightness, L* | 0.03 | -0.20 | 0.27 | -0.15 | -0.35 | 0.06 | 0.25 |
| Redness, a* | 0.12 | -0.11 | 0.35 | 0.38 | 0.19 | 0.55 | 0.09 |
| Yellowness, b* | 0.09 | -0.14 | 0.32 | 0.08 | -0.13 | 0.28 | 0.92 |
| Color | 0.62 | 0.44 | 0.74 | 0.49 | 0.31 | 0.64 | 0.27 |
| Marbling | 0.33 | 0.11 | 0.53 | 0.40 | 0.21 | 0.56 | 0.65 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]Aged postmortem traits were evaluated 14 d postmortem

[3]Probablity value comparing correlation coefficients of meat quality traits between barrows and gilts

**Table 2.6.** Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem instrumental yellowness (b*) values with aged loin quality and chop quality of barrows and gilts[1,2]

| | Barrow b* | | | Gilt b* | | | |
|---|---|---|---|---|---|---|---|
| | | 95% Confidence limit | | | 95% Confidence limit | | |
| Aged postmortem variable | Rho | Lower | Upper | Rho | Lower | Upper | *P* - value[3] |
| *Loin* | | | | | | | |
| Loin pH | -0.47 | -0.64 | -0.27 | -0.60 | -0.72 | -0.44 | 0.29 |
| Ventral lightness, L* | 0.36 | 0.14 | 0.55 | 0.42 | 0.23 | 0.58 | 0.68 |
| Ventral redness, a* | 0.05 | -0.19 | 0.28 | 0.31 | 0.11 | 0.49 | 0.09 |
| Ventral yellowness, b* | 0.10 | -0.14 | 0.33 | 0.36 | 0.17 | 0.53 | 0.09 |
| Ventral color | -0.61 | -0.74 | -0.43 | -0.45 | -0.60 | -0.27 | 0.19 |
| Ventral marbling | -0.23 | -0.44 | 0.01 | -0.31 | -0.49 | -0.11 | 0.58 |
| Ventral firmness | -0.24 | -0.45 | -0.01 | -0.22 | -0.41 | -0.01 | 0.90 |
| *Chop* | | | | | | | |
| Lightness, L* | -0.08 | -0.31 | 0.16 | -0.11 | -0.31 | 0.10 | 0.87 |
| Redness, a* | -0.13 | -0.35 | 0.11 | -0.22 | -0.41 | -0.01 | 0.56 |
| Yellowness, b* | -0.09 | -0.32 | 0.15 | -0.23 | -0.42 | -0.03 | 0.35 |
| Color | -0.51 | -0.67 | -0.32 | -0.53 | -0.67 | -0.36 | 0.87 |
| Marbling | -0.17 | -0.39 | 0.07 | -0.31 | -0.49 | -0.10 | 0.37 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]Aged postmortem traits were evaluated 14 d postmortem

[3]Probablity value comparing correlation coefficients of meat quality traits between barrows and gilts

**Table 2.7.** Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem subjective color values with aged loin quality and chop quality of barrows and gilts[1,2]

| | Barrow color | | | Gilt color | | | |
|---|---|---|---|---|---|---|---|
| | | 95% Confidence limit | | | 95% Confidence limit | | |
| Aged postmortem variable | Rho | Lower | Upper | Rho | Lower | Upper | *P* - value[3] |
| *Loin* | | | | | | | |
| Loin pH | -0.04 | -0.21 | 0.14 | 0.06 | -0.08 | 0.20 | 0.40 |
| Ventral lightness, L* | -0.23 | -0.39 | -0.06 | -0.28 | -0.41 | -0.15 | 0.61 |
| Ventral redness, a* | 0.28 | 0.11 | 0.43 | 0.05 | -0.10 | 0.19 | 0.04 |
| Ventral yellowness, b* | -0.03 | -0.21 | 0.15 | -0.20 | -0.34 | -0.06 | 0.13 |
| Ventral color | 0.15 | -0.03 | 0.31 | -0.02 | -0.16 | 0.13 | 0.16 |
| Ventral marbling | -0.04 | -0.22 | 0.14 | 0.10 | -0.04 | 0.24 | 0.22 |
| Ventral firmness | -0.14 | -0.31 | 0.03 | 0.06 | -0.09 | 0.19 | 0.09 |
| *Chop* | | | | | | | |
| Lightness, L* | -0.04 | -0.22 | 0.14 | -0.14 | -0.28 | 0.01 | 0.41 |
| Redness, a* | -0.12 | -0.30 | 0.06 | 0.02 | -0.13 | 0.17 | 0.22 |
| Yellowness, b* | -0.06 | -0.23 | 0.13 | 0.02 | -0.13 | 0.16 | 0.56 |
| Color | 0.13 | -0.05 | 0.30 | 0.11 | -0.04 | 0.25 | 0.87 |
| Marbling | -0.12 | -0.29 | 0.06 | -0.03 | -0.18 | 0.12 | 0.46 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]Aged postmortem traits were evaluated 14 d postmortem

[3]Probablity value comparing correlation coefficients of meat quality traits between barrows and gilts

**Table 2.8.** Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem subjective marbling

values with aged loin quality and chop quality of barrows and gilts[1,2]

| | Barrow marbling | | | Gilt marbling | | | |
|---|---|---|---|---|---|---|---|
| | | 95% Confidence limit | | | 95% Confidence limit | | |
| Aged postmortem variable | Rho | Lower | Upper | Rho | Lower | Upper | *P* - value[3] |
| *Loin* | | | | | | | |
| Loin pH | 0.35 | 0.19 | 0.50 | 0.24 | 0.10 | 0.37 | 0.29 |
| Ventral lightness, L* | -0.15 | -0.32 | 0.03 | -0.13 | -0.26 | 0.02 | 0.85 |
| Ventral redness, a* | 0.01 | -0.17 | 0.18 | 0.02 | -0.12 | 0.16 | 0.92 |
| Ventral yellowness, b* | -0.03 | -0.20 | 0.15 | -0.06 | -0.20 | 0.08 | 0.74 |
| Ventral color | 0.42 | 0.27 | 0.56 | 0.30 | 0.16 | 0.42 | 0.21 |
| Ventral marbling | 0.67 | 0.56 | 0.75 | 0.66 | 0.57 | 0.73 | 0.86 |
| Ventral firmness | 0.08 | -0.10 | 0.25 | 0.26 | 0.13 | 0.39 | 0.10 |
| *Chop* | | | | | | | |
| Lightness, L* | 0.16 | -0.02 | 0.34 | 0.06 | -0.09 | 0.20 | 0.36 |
| Redness, a* | 0.06 | -0.12 | 0.24 | 0.25 | 0.11 | 0.39 | 0.09 |
| Yellowness, b* | 0.03 | -0.15 | 0.21 | 0.16 | 0.02 | 0.31 | 0.27 |
| Color | 0.37 | 0.21 | 0.52 | 0.30 | 0.16 | 0.42 | 0.45 |
| Marbling | 0.57 | 0.43 | 0.68 | 0.59 | 0.48 | 0.67 | 0.83 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]Aged postmortem traits were evaluated 14 d postmortem

[3]Probablity value comparing correlation coefficients of meat quality traits between barrows and gilts

**Table 2.9.** Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem loin quality traits between barrows and gilts with Warner-Bratzler shear force (WBSF) and cook loss[1,2]

| | Barrow WBSF | | | Gilt WBSF | | | |
|---|---|---|---|---|---|---|---|
| | | 95% Confidence limit | | | 95% Confidence limit | | |
| Early postmortem variable | Rho | Lower | Upper | Rho | Lower | Upper | *P* - value[3] |
| *WBSF* | | | | | | | |
| Loin pH | 0.27 | 0.09 | 0.43 | 0.09 | -0.05 | 0.24 | 0.13 |
| Ventral lightness, L* | -0.22 | -0.43 | 0.02 | -0.26 | -0.44 | -0.05 | 0.82 |
| Ventral redness, a* | 0.08 | -0.16 | 0.31 | -0.17 | -0.37 | 0.04 | 0.12 |
| Ventral yellowness, b* | -0.22 | -0.43 | 0.02 | -0.05 | -0.26 | 0.16 | 0.31 |
| Ventral color | 0.00 | -0.18 | 0.18 | -0.05 | -0.19 | 0.10 | 0.71 |
| Ventral marbling | 0.13 | -0.05 | 0.30 | 0.00 | -0.15 | 0.14 | 0.27 |
| Ventral firmness | 0.18 | -0.01 | 0.35 | -0.07 | -0.21 | 0.08 | 0.04 |
| *Cook Loss, %* | | | | | | | |
| Loin pH | -0.25 | -0.41 | -0.08 | -0.41 | -0.53 | -0.28 | 0.13 |
| Ventral lightness, L* | 0.08 | -0.16 | 0.31 | -0.01 | -0.22 | 0.20 | 0.57 |
| Ventral redness, a* | -0.22 | -0.43 | 0.02 | -0.24 | -0.43 | -0.03 | 0.89 |
| Ventral yellowness, b* | 0.17 | -0.07 | 0.39 | 0.45 | 0.27 | 0.61 | 0.05 |
| Ventral color | 0.03 | -0.15 | 0.21 | 0.02 | -0.13 | 0.16 | 0.89 |
| Ventral marbling | -0.25 | -0.41 | -0.07 | -0.21 | -0.34 | -0.07 | 0.72 |
| Ventral firmness | -0.21 | -0.37 | -0.03 | -0.26 | -0.39 | -0.12 | 0.64 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]Chops for Warner-Bratzler shear force and cook loss were aged for 14 d postmortem prior to analyses

[3]Probablity value comparing correlation coefficients of meat quality traits between barrows and gilts

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# Chapter 3

## GROWTH PERFORMANCE, CARCASS QUALITY, FRESH BELLY CHARACTERISTICS, AND COMMERCIAL BACON SLICING YIELDS OF GROWING-FINISHING PIGS FROM SIRE LINES INTENDED FOR DIFFERENT INDUSTRY APPLICATIONS


### ABSTRACT

The objective was to control intrinsic and extrinsic factors associated with the production and slaughter of pigs to determine effects of sire line (Pietrain vs. Duroc ancestry) on growth performance, carcass and belly characteristics, and commercial bacon yields of growing-finishing pigs. A total of 320 barrows and gilts were used. Offspring shared a common dam line and all environmental contributions to variation were controlled. Pigs were housed in single-sex pens by sire line. Pigs were slaughtered at the end of a 3-phase, 98 d feeding program. There were no differences in growth performance ($P \geq 0.08$) or belly processing characteristics ($P \geq 0.09$). Pietrain sired pigs had a greater lean yield ($P \leq 0.01$). Duroc sired pigs had darker, more highly marbled loins ($P \leq 0.04$) and thicker bellies ($P < 0.001$). Bacon from Pietrain sired pigs had a greater ($P = 0.04$) lean to fat ratio with 1.58% increase ($P = 0.04$) in average bacon slice lean.



**Keywords:** belly quality, genotype, loin quality, pork, quality, sire line

## INTRODUCTION

Pork is the number one consumed animal protein in the world with more than 91% of all pork and pork variety meats consumed outside of the United States (National Pork Board, 2017). Today, the U.S. accounts for approximately 31% of the world's pork exports and exports 2.45 million metric tons of pork and pork products annually (National Pork Board, 2017; U.S. Meat Export Federation, 2018). Mexico and Japan are currently the two largest importers of U.S. pork while China is the largest importer of U.S. pork variety meats (U.S. Meat Export Federation, 2018). Mexico is the largest importer of fresh pork on a volume basis (441,558 metric tons; $780,254) while Japan is the largest importer on a value basis (256,058 metric tons; $1,071,844). For both Mexican and Japanese consumers, initial purchase intent is most influenced by visual quality traits (Ngapo et al., 2007; Ngapo et al., 2017). However, emphasis placed on each trait varies based on individual preference (Moeller et al., 2010). Mexican consumers prefer a high lean product and Japanese consumers prefer a darker, more highly marbled product. Contrasting demands of a growing export market have required producers to re-evaluate breeding objectives. As a result, pork quality and carcass characteristics are now essential breeding objectives and integrated into many breeding programs in order to meet specific requirements of distinct markets (lean growth vs. meat quality; Miar et al., 2014). Previously, a study by Arkfeld et al. (2016) characterized carcass and quality characteristics from two different populations of pigs; one population was destined for a quality-focused market and the other for a lean-focused market. However, the study did not control breed of pig, diet, environment, transport duration, or lairage time at the slaughter facility. Carcass characteristics and meat quality are influenced by both intrinsic and extrinsic factors. Failure to control these factors make it difficult to separate true differences associated with sire lines from differences associated with extrinsic factors.

Therefore, the objective of this study was to control both inherent and environmental factors in order to determine specific effects of sire line (lean vs. quality) on growth performance, carcass characteristics, fresh belly quality, and commercial bacon slicing yields of growing-finishing pigs.

## MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol for this experiment.

### *Experimental design*

A total of 320 pigs (160 barrows and 160 gilts) were the offspring of either Pietrain (P81) or Duroc (P26) ancestry (Choice Genetics USA, West Des Moines, IA). Boars were mated with Camborough sows (Pig Improvement Company, Hendersonville, TN) and parity of the females were balanced among sire lines. Pigs were used in a randomized complete block design with a 2 × 2 factorial arrangement of treatments. Pigs were housed in single-sex pens by sire line. Each pen housed 4 pigs and there were 80 total pens in the experiment. Pigs were sourced from 2 farrowing groups (20 sows per block) that were born approximately two weeks apart. This resulted in 2 experimental blocks of pigs based on farrowing group. Each block consisted of 40 total pens with 10 replications per sire line and sex combination. Pigs were randomly allotted to pens at 10 weeks of age based on initial body weight (**BW**) and sex.

Pigs were housed in a mechanically ventilated building with partially slatted concrete floors for the entire feeding period. Each pen was 1.83 m x 2.59 m (1.18 $m^2$/pig) and had a single-space, dry-box feeder mounted on the front gate and one nipple drinker. Ambient temperature was maintained using controlled heaters and fan ventilation.

A 3-phase, 98 d feeding program was used. Day 0 of the experiment was the first day of the grower phase and beginning of the feeding portion of the trial. Pens of pigs were fed a grower diet from d 0 to d 35, an early finisher diet from d 36 to d 70, and a late finisher diet from d 71 to d 98. All 3 diets were formulated to be iso-caloric and contained no ractopamine hydrochloride or dried distillers grains with or without solubles. Pigs were weighed at the beginning of the feeding period (d 0) and again at the end of each of the 3 feeding phases. Daily feed allotments were recorded and data were summarized to calculate ADG, ADFI, and G:F. Day 98 for each block was considered the end of the feeding portion of the trial and all pigs were weighed in order to calculate overall ADG, ADFI, and G:F. On d 98, the heaviest pig from each pen (40 total pigs) was removed and transported to the University of Illinois Meat Science Laboratory (Urbana, IL) for slaughter on d 99. Also on d 99, the second heaviest and lightest pigs from each pen (80 total pigs) were removed and transported to a commercial scale federally inspected abattoir. The remaining pig (third heaviest) was slaughtered at the University of Illinois Meat Science Laboratory on d 101.

***University of Illinois Meat Science Laboratory slaughter and carcass characteristics***

The pigs transported to the University of Illinois Meat Science Laboratory (Urbana, IL) were held in lairage for at least 16 hours before slaughter. Pigs were provided ad libitum access to water but had no access to feed during this time. Pigs were weighed immediately before slaughter to determine an ending live weight (**ELW**). Pigs were slaughtered under the supervision of the Food Safety and Inspection Service of the United States Department of Agriculture (**USDA**). Pigs were immobilized using head-to-heart electrical stunning and terminated via exsanguination. Carcasses were weighed approximately 45 min postmortem to determine hot carcass weight (**HCW**). Carcass yield was calculated by dividing the HCW by ending live weight and expressed as a percentage.

Carcasses were chilled at 4°C for a minimum of 20 hours. Estimates of carcass composition were determined on the left side of each carcass, which was separated between the $10^{th}$ and $11^{th}$ rib to expose the longissimus thoracis (**LTL**). Tenth-rib back fat thickness was measured at ¾ the distance of the LTL from the dorsal process of the vertebral column. Loin eye area (**LEA**) was measured by tracing the surface of the LTL on acetate paper. The LTL tracings were measured in duplicate using a digitizer tablet (Wacom, Vancouver, WA) and Adobe Photoshop CS6. The average of the two measurements was reported as LTL area. Standardized fat-free lean percentage was calculated using the equation (8.588 + (0.465 × HCW, lb) – (21.896 × fat thickness, in) + (3.005 × loin muscle area, $in^2$)) / HCW, lb) × 100 as described in procedure 1 for ribbed carcasses (Burson and Berg, 2001).

***Carcass fabrication***

At 1d postmortem, the left side of each chilled carcass was weighed and then fabricated into a pork leg (NAMP #401), skin-on whole loin, pork shoulder (NAMP #403), neck bones (NAMP #421), jowl (NAMP #419), skin-on natural fall belly (NAMP #408), and spareribs (NAMP #416) to meet the specifications as described in the North American Meat Institute Meat Buyer's Guide (**NAMI**, 2014). Each primal piece was weighed before further fabrication. Legs were skinned and trimmed of fat to meet the specifications of a NAMP #402 trimmed ham. Further fabrication of the hams followed the method outlined by Boler et al. (2012). The loin was separated into an anterior and posterior portion, due to the separation at the location of the $10^{th}$ and $11^{th}$ rib to assess carcass composition. The anterior and posterior portions of the loin were skinned and trimmed of fat to meet the specifications of a NAMP #410 bone-in loin. Both halves of the trimmed, bone-in loin were weighed, as a set, to determine the weight of the whole skinless bone-in loin. Both the anterior and posterior portions were then fabricated, and weighed as a set, to meet the specifications of a NAMP #414 Canadian back loin, a NAMP #415A tenderloin, and a NAMP #413D sirloin. The whole shoulder was skinned and trimmed of fat to meet the specifications of a skinned pork shoulder (NAMP #404). The Boston butt was separated from the picnic to form a NAMP #406 bone-in Boston butt and a NAMP #405 bone-in picnic, and then weighed individually. The bones were removed from each piece to meet the specifications of a NAMP #406A boneless Boston butt and a NAMP #405A boneless picnic with the triceps brachii (shoulder cushion) attached. Carcass cutability was expressed as a percentage of chilled left side weight to account for variability in BW and HCW. The following equations were used to calculate cutability:

*Bone-in lean cutting yield, % = [(trimmed ham (NAMP #402), kg + bone-in trimmed Boston butt (NAMP #406), kg + bone-in picnic (NAMP #405), kg + trimmed loin (NAMP #410), kg) / chilled left side weight, kg]×100*

*Bone-in carcass cutting yield, % = [(bone-in lean cutting yield components + natural fall belly (NAMP #408), kg) / chilled left side weight, kg] × 100*

*Boneless carcass cutting yield, % = [(inside ham (NAMP #402F), kg + outside ham (NAMP #402E), kg + knuckle (NAMP #402H), kg) + inner shank, kg + lite butt, kg + Canadian back (NAMP #414), kg +tenderloin (NAMP #415A), kg + sirloin (NAMP #413D), kg) + boneless Boston butt (NAMP #406A), kg + boneless picnic (NAMP #405A), kg + natural fall belly (NAMP #408), kg)) / chilled left side weight] × 100*

Natural fall bellies and Canadian back loins were collected to assess both fresh belly quality and fresh and aged loin quality.

***Early postmortem loin quality evaluation***

At 1 d postmortem, quality measurements for instrumental color, visual color, visual marbling, subjective firmness, and ultimate pH were conducted by trained University of Illinois personnel. Loins were re-faced and evaluated for quality parameters on the cut surface of the LTL posterior to the $10^{th}$ rib. Oxygenation of myoglobin occurred at 4°C for approximately 20 minutes before quality measurements were evaluated. Instrumental L*(lightness), a* (redness), and b* (yellowness; CIE 1978) were measured with a Minolta CR-400 Chroma meter (Minolta Camera Co., Ltd., Osaka, Japan) using a D65 light source, 2° observer angle, an 8 mm aperture, and calibrated using a white tile. Brewer et al. (2001) reported that time of oxygen exposure from 0 min through 30 min had no effect on instrumental L* while instrumental a* values did not change after 10 min of oxygen. Thus, 20 min was sufficient to allow for appropriate oxygenation of myoglobin. Ultimate pH was measured on the ventral side of the LTL muscle in the approximate location of the 10th rib using a Reed data logger, calibrated at 4°C, fitted with a Hanna glass electrode (REED SD-230 Series pH/ORP Datalogger, 0.00 to 14.00 pH/0-199 mV; Hanna FC200B electrode). Visual color and marbling scores (NPPC, 1999), and subjective firmness scores (NPPC, 1991) were determined by a single technician. After 1d postmortem quality measures were complete, loins were vacuum packaged and aged for 13 d at 4°C.

***Aged postmortem loin quality evaluation***

At 14 d postmortem, loins were removed from the packaging, allowed to drip for approximately 20 minutes, and weighed. Purge loss (%) was calculated using the following equation:

*Purge Loss, % = [(1 d weight, kg – 14 d weight, kg) / 1 d weight, kg] ×100*

Loins were exposed to oxygen for at least 20 min and then quality measurements for instrumental color, visual color, visual marbling, subjective firmness, and aged ultimate pH were conducted on the ventral surface of the loins, using the same procedures as the 1 d postmortem quality evaluations. Ambient room temperature during evaluations was approximately 4°C. After quality evaluations were completed on the ventral surface of the loins, three loin chops from each loin were removed, posterior to the cut at the $10^{th}$ rib, for evaluation of proximate composition (moisture and extractable lipid), cook loss, and Warner-Bratzler shear force (**WBSF**). Chops were sliced into 2.54 cm thick chops using a Bizerba deli slicer SE 12 D US (Bizerba USA Inc. Piscataway, NJ). Chop 1 was exposed to oxygen for at least 20 minutes before evaluation. Then, instrumental L*(lightness), a* (redness), and b* (yellowness; CIE 1978) were measured with a Minolta CR-400 Chroma meter (Minolta Camera Co., Ltd., Osaka, Japan) using a D65 light source, 2° observer angle, an 8 mm aperture, and calibrated using a white tile. Visual color and marbling scores (NPPC, 1999), and subjective firmness scores (NPPC, 1991) were determined by a single technician. Chop 1 was then trimmed free of all subcutaneous fat and secondary muscles, packaged in Whirl-Pak bags (Nasco, Ft. Atkinson, WI), and stored at -2°C until determination of moisture and extractable lipid. Chop 2 was vacuum packaged and stored at -2°C until determination cook loss (%) and WBSF. Chop 3 was vacuum packaged and stored at -2°C as a backup sample.

***Cook Loss and Warner-Bratzler Shear Force***

The 2.54 cm thick chops were removed from the freezer at least 24 h prior to analysis and allowed to thaw thoroughly at approximately 1°C. Chops were individually weighed and then cooked on a Farberware Open Hearth grill (model 455N, Walter Kidde, Bronx, NY, USA).

Chops were cooked, on one side, to an internal temperature of 31.5°C, flipped, and then cooked until they reached an internal temperature of 63°C, at which point they were removed. Internal temperature, during cooking, was monitored using copper-constantan thermocouples (Type T, Omega Engineering, Stamford, CT, USA) placed in the approximate geometric center of each chop and connected to a digital scanning thermometer (model 92000-00, Barnat Co, Barrington, IL). Chops were allowed to cool to approximately 25°C, and weighed again to determine percent cook loss. Five 1.25 cm diameter cores were removed parallel to the orientation of the muscle fibers and sheared using a Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, NY/Stable Mirosystems, Godalming, UK) with a blade speed of 3.33 mm/s and a load cell capacity of 100 kg. The shear force value for the 5 cores were averaged and the average was reported as Warner-Bratzler shear force.

***Loin proximate composition***

Individual, trimmed loin chops were packaged in Whirl-Pak bags (Nasco, Ft. Atkinson, WI) and stored at -2°C until analysis. Loin chops were thawed at 25°C and then homogenized in a Cuisinart (East Windsor, NJ) food processor. Duplicate 10 g samples from each loin chop were placed in a drying oven set at 110°C for at least 24 h. Moisture and extractable lipid content were determined using the chloroform-methanol solvent method described by Novakofski et al. (1989).

***Fresh belly characteristics***

An adipose tissue sample for fatty acid profile analyses was collected from the dorsal edge of the anterior end of each belly. The sample was free of lean and contained all 3 layers of adipose tissue. Fresh bellies were evaluated for length at the midpoint of the latitudinal axis and width at the midpoint of the longitudinal axis. Belly thickness was calculated as the mean of 8 individual locations of the belly. Thickness at each location was determined by forcing a sharpened probe through the lean side of the belly. Measurements 1 to 4 were collected at the midpoint between the latitudinal axis and the dorsal edge at 20%, 40%, 60%, and 80% of the length of the belly starting at the anterior end. Measurements 5 to 8 were collected at the midpoint between the longitudinal axis and the ventral edge at 20%, 40%, 60%, and 80% of the length of the belly starting at the anterior end. Flop distance was determined by placing the bellies skin side down, over a stationary bar, and measuring the distance between the inside edges. After fresh belly quality had been evaluated, bellies were vacuum packaged and stored at -34°C for approximately 74 d until they were manufactured into bacon.

***Bacon manufacturing and slicing***

Frozen, vacuum packaged bellies were allowed to thaw at 4°C for approximately 4 d. Thawed bellies were skinned, yielding an NAMP #409 skinless belly, and then weighed to determine initial weight (green weight). Bellies were repackaged and transported in a refrigerated truck to a USDA federally inspected bacon manufacturing facility for further processing. Bellies were injected with a typical commercial cure solution formulated to deliver 1.5% sodium chloride (salt) in the final product with a target pump uptake of 13%. Bellies were weighed immediately after injection to calculate pump uptake using the following equation:

*Pump Uptake = [(pumped weight – initial weight) / initial weight] × 100*

Injected bellies were hung on smoke house racks and thermally processed to an internal temperature of 53.3°C. Bellies were chilled for approximately 24 h before slicing, and ultimately reached an internal temperature between -5.6°C and -4.4°C. Chilled bellies were weighed to calculate cooked yield using the following equation:

*Cooked yield = [(cooked weight – initial weight) / initial weight] × 100*

Bellies were pressed and then sliced, anterior end first, to obtain a target of 22 to 27 slices per kg (10 to 12 slices per pound). Slices were sorted by trained personnel, based on grading procedures of the manufacturer, to remove incomplete slices, end pieces, and slices of unacceptable quality. Sliced bacon slabs were placed on U-boards and vacuum packaged individually such that anatomical orientation was maintained with 1 sliced bacon slab per package. Sliced bacon slabs were then transported to the University of Illinois Meat Science Laboratory for further analysis.

***Sliced bacon characteristics***

Individual sliced weight of each sliced bacon slab was recorded to calculate commercial slicing yield from initial weight and cooked weight using the following equations:

*Slice yield (initial) = (sliced weight / initial weight) × 100*

*Slice yield (cooked) = (sliced weight / cooked weight) × 100*

Total number of slices were counted and recorded for each sliced bacon slab. Starting at the anterior portion, sliced bacon slabs were divided into 5 equal zones (A, B, C, D, E) with approximately equal slices in each zone similar to Kyle et al. (2014) and Tavárez et al. (2014).

***Bacon proximate composition***

Two bacon slices from each zone of the sliced bacon slab (A through E) were collected, packaged in Whirl-Pak bags (Nasco, Ft. Atkinson, WI), and stored at -2°C until analysis. Slices (10 total) were thawed, then cut into small pieces and homogenized together in a Cuisinart food processor (CUI DFP-7BC; Cuisinart, East Windsor, NJ). Moisture and extractable lipid content were determined using the chloroform-methanol solvent method described by Novakofski et al., (1989).

***Bacon slice lean:fat image analysis***

Slices were identified based on anatomical location as blade end (25% of the length of the belly from the anterior end or zone A), middle (50% or zone C), and flank end (75% or zone E). Slices were photographed as a set using a Nikon D60 camera (Nikon Instruments Inc., Melville, NY) at a standardized distance from the samples. Images were converted to a black and white TIFF (tagged image file format) file in Adobe Photoshop CC 2018 (Adobe Systems Inc., San Jose, CA) where the individual slice outlines were selected using the magic wand tool. Image analysis was also conducted using Adobe Photoshop CC 2018 similar to the method outlined by Abramoff et al. (2004). A ruler was included in each image to allow for the establishment of known distance. Threshold values were adjusted as needed within each image to account for variations in lean and fat color. Total slice length, width, and area were calculated using Adobe Photoshop CC 2018. Primary lean and secondary lean (cutaneous trunci [Person et al., 2005]) area was also calculated by Adobe Photoshop CC 2018.

***Commercial abattoir slaughter and carcass characteristics***

The second heaviest and lightest pigs (80 total pigs) from each original pen of pigs were slaughtered at a federally inspected abattoir under the supervision of the USDA Food Safety and Inspection Service. Each pig was tattooed on the ham with a unique number prior to transportation to the abattoir. Pigs were transported approximately 34 km and held in lairage for a minimum of 3 h prior to slaughter. Pigs were immobilized via carbon dioxide gas and terminated by exsanguination. Individual tattoo was recorded so that it could be matched with HCW. Hot carcass weight was recorded immediately before each carcass entered a blast chiller. Following the approximately 90 min blast-chill, carcasses were transferred to an equilibration cooler. While in the equilibration cooler, back-fat thickness was determined by measuring the midline fat thickness at the 10th rib. Standardized fat-free lean percentage was calculated using the equation ((23.568 + (0.503 × HCW, lb) – (21.348 × fat thickness, in))/HCW) × 100 as described in procedure 2 for unribbed carcasses (Burson & Berg, 2001).

***Statistical analysis***

Data were analyzed using the MIXED procedure of SAS (SAS Inst. In., Cary, NC) as a 2 × 2 factorial arrangement (sire line × sex) of treatments in a randomized complete block design. Pen (80 total) served as the experimental unit for all fixed variables.  Fixed effects were sire line, sex, and the interaction between sire line and sex.  Block (n = 2) served as random variable. Effect of sire line, sex, and the interaction between sire line and sex was considered significant at $P < 0.05$.  Least squares means were separated using a probability of difference (**PDIFF**) statement in the MIXED procedure of SAS.  Normality of residuals was tested using the UNIVARIATE procedure of SAS.  Homogeneity of variances was tested using the Levene's hovtest option in the GLM procedure of SAS.

**RESULTS**

***Body weight, average daily gain, and average daily feed intake***

There were no interactions ($P \geq 0.11$) for sire line and sex within the three dietary phases (**Table 3.1**). Body weight for d 0 ($P = 0.98$), d 35 ($P = 0.63$), d 70 ($P = 0.43$), or d 98 ($P = 0.62$) did not differ between Duroc and Pietrain sired pigs.  At the start of the experiment (d 0), there was no difference ($P = 0.85$) in BW between barrows and gilts, but were different ($P < 0.001$) by the end of the first phase. Barrows were heavier than gilts during phase 2 and phase 3 ($P < 0.001$) and were 8.52 kg heavier than gilts at the end of the experiment (d 98). For phase 1, Duroc sired pigs had a greater ($P = 0.02$) ADFI and were less efficient ($P < 0.001$) compared with Pietrain sired pigs, but ADG did not differ ($P = 0.73$) between the two sire lines. For phase

2, Duroc and Pietrain sired pigs did not differ in ADG ($P$ = 0.60), ADFI ($P$ = 0.09), or G:F ($P$ = 0.56). For phase 3, Duroc sired pigs had a greater ($P$ < 0.01) ADFI compared with Pietrain sired pigs however, there were no differences in ADG ($P$ = 0.51) and G:F ($P$ = 0.48) between the two sire lines. Barrows had a greater ADG and ADFI compared with gilts for both phase 1 ($P$ < 0.001) and phase 2 ($P$ < 0.001), but G:F did not differ ($P \geq 0.53$) between sex for either phase. For phase 3, barrows had a greater ($P$ < 0.001) ADFI compared with gilts, but there were no differences in ADG ($P$ = 0.29) or G:F ($P$ = 0.10) between sex. The cost per kg of gain did not differ ($P \geq 0.40$) between barrows and gilts for the first two dietary phases however, the cost per kg of gain was greater ($P$ < 0.01) for barrows than gilts in phase three. Duroc sired pigs had a greater ($P$ < 0.001) cost per kg of gain during the first phase, but did not differ ($P \geq 0.18$) from Pietrain sired pigs for the other two dietary phases. Overall, ADG ($P$ = 0.96) and ADFI ($P$ = 0.08) did not differ between Duroc and Pietrain sired pigs however, Duroc sired pigs had a greater ($P$ = 0.04) overall cost per kg of gain compared with Pietrain sired pigs.  Barrows grew 8.3% faster (P < 0.001) and consumed 12.5% more feed ($P$ < 0.001) than gilts throughout the 98 d experiment, and had a greater ($P$ < 0.01) overall cost per kg of gain than gilts. There was an interaction between sire line and sex for overall G:F. Pietrain and Duroc sired gilts were more efficient ($P \leq 0.01$) than Pietrain sired barrows however, feed efficiency did not differ ($P$ = 0.07) between Duroc sired barrows and gilts, and did not differ ($P$ = 0.46) between Duroc and Pietrain sired barrows.

***Carcass characteristics and cutability***

There were no interactions ($P \geq 0.23$) for carcass characteristics between sire line and sex (**Table 3.2**). There were no differences in ending live weight ($P$ = 0.72) or HCW ($P$ = 0.50) between Duroc and Pietrain sired pigs.  Carcass yield of Duroc sired pigs was 0.49 units greater

($P < 0.01$) than that of Pietrain sired pigs. Loin eye area did not differ ($P = 0.85$) between the two sire lines however, carcasses from Duroc sired pigs had 0.32 cm more ($P < 0.001$) 10$^{th}$ rib fat thickness and 1.32 percentage units less ($P < 0.01$) standardized fat-free lean compared with carcasses from Pietrain sired pigs. Barrows had a greater ELW ($P < 0.001$), HCW ($P < 0.001$), and carcass yield ($P < 0.001$) compared with gilts. Carcasses from barrows and gilts did not differ ($P = 0.94$) in LEA however, carcasses from gilts had 0.34 cm less ($P < 0.001$) 10$^{th}$ rib fat thickness and 1.96 percentage units more ($P < 0.001$) standardized fat-free lean than carcasses from barrows.

***Whole and trimmed primal cuts***

There were no interactions for whole and trimmed primal cutability estimates expressed as absolute weights ($P \geq 0.06$) between sire line and sex (**Table 3.3**). There was an interaction between sire line and sex for percent chilled side weights of the whole shoulder ($P = 0.01$), bone-in Boston butt ($P < 0.01$), whole loin ($P = 0.02$), and spareribs ($P = 0.01$). Percent chilled side weight of the whole shoulder was greater ($P = 0.01$) in Pietrain sired gilts compared with Pietrain sired barrows. There was no difference ($P = 0.12$) in percent chilled side weight of the whole shoulder between Duroc sired barrows and gilts. Percent of chilled side weight of bone-in Boston butts from Pietrain sired gilts was 0.50 percentage units greater ($P < 0.001$) than Duroc sired gilts, but there was no difference ($P = 0.93$) in percent chilled side weight of bone-in Boston butts between Duroc and Pietrain sired barrows. Whole loin percent of chilled side weight was 0.59 percentage units greater ($P = 0.01$) in Duroc sired gilts than Pietrain sired gilts. Percent of chilled side weight of the whole loin was not different ($P = 0.36$) between Pietrain and Duroc sired barrows. Percent chilled side weight of spareribs was 0.13 percentage units greater ($P = 0.04$) in Pietrain sired gilts than Duroc sired gilts. Percent chilled side weight of spareribs was not different ($P$ = 0.10) between Pietrain and Duroc sired barrows. Trimmed loin percent of chilled side weight was 0.68 percentage units greater ($P$ = 0.02) in Pietrain sired pigs compared with Duroc sired pigs. No other whole or trimmed primal cutability estimates expressed as absolute weights or as a percentage of chilled side weight differed ($P \geq 0.09$) between Duroc and Pietrain sired pigs. Barrows had a heavier ($P$ < 0.001) chilled carcass side weight compared with gilts. Whole shoulder weight was greater ($P$ < 0.001) in barrows than gilts, but percent of chilled side weight did not differ between sex ($P$ = 0.49). Weights for whole and trimmed primal cuts were heavier ($P$ < 0.001) with the exception of the trimmed ham. Trimmed ham weight did not differ ($P$ = 0.07) between barrows and gilts. Percent of chilled side weight of the trimmed loin and trimmed ham was greater ($P$ < 0.01) in gilts compared with barrows. Percent of chilled side weight of the bone-in picnic ($P$ = 0.65) and ($P$ = 0.69) belly did not differ between barrows and gilts.

***Ham cuts***

There were no interactions for ham cuts expressed either as absolute weights ($P \geq 0.30$) or as a percentage of the chilled left side ($P \geq 0.09$) between sire line and sex (**Table 3.4**). Weight of the knuckle was greater ($P$ < 0.001) in Pietrain sired pigs compared with Duroc sired pigs. No other whole primal cutability estimates expressed as absolute weights differed between Duroc and Pietrain sired pigs ($P \geq 0.07$). Pietrain sired pigs had a greater percent of chilled side weight for the inside ham ($P$ = 0.02) and knuckle ($P$ < 0.001). Percent of chilled side weight for the outside ham, inner shank, lite butt, and boneless ham did not differ ($P \geq 0.31$) between the two sire lines. Weights for the inside ham, outside ham, ham knuckle, lite butt, and boneless ham did not differ between sex ($P \geq 0.09$). Weight of the inner shank was greater ($P$ < 0.001) in barrows compared with gilts. Percent of chilled side weight for all ham cuts was greater ($P$ <

0.01) for gilts compared with barrows, with the exception of the inner shank and boneless ham. Percent of chilled side weight of the inner shank and boneless ham did not differ ($P \geq 0.26$) between barrows and gilts.

***Shoulder cuts***

There was an interaction between sire line and sex for percent of chilled side weight of both the boneless Boston ($P < 0.01$) and the boneless shoulder ($P < 0.01$) (**Table 3.5**). Pietrain sired gilts had a greater ($P < 0.001$) percent of chilled side weight of the boneless Boston butt than Duroc sired gilts. Percent of chilled side weight for the boneless shoulder was also greater ($P < 0.001$) in Pietrain sired gilts than Duroc sired gilts. Percent of chilled side weight for both the boneless Boston butt and boneless shoulder did not differ ($P \geq 0.61$) between Pietrain and Duroc sired barrows. There were no other interactions between sire line and sex for percent of chilled side weight ($P \geq 0.09$) of shoulder cuts. There was an interaction for jowl weight ($P = 0.04$) between sire line and sex as jowl weight was greater ($P = 0.01$) in Pietrain sired barrows compared with Duroc sired barrows. Jowl weight did not differ ($P = 0.72$) between Pietrain and Duroc sired gilts. There were no other interactions for shoulder cuts expressed as an absolute weight ($P \geq 0.09$). Weight of the boneless Boston butt was greater ($P = 0.02$) in Pietrain sired pigs than Duroc sired pigs. Both the weight and the percent of chilled side weight of the front knee was greater ($P \leq 0.03$) in Duroc sired pigs than Pietrain sired pigs. Absolute weights for the boneless picnic, neckbones, and boneless shoulder did not differ ($P \geq 0.13$) between the two sire lines. There were also no differences ($P \geq 0.06$) in the percent of chilled side weight of the boneless picnic, neckbones, and jowl between the two sire lines. Absolute weights of the boneless Boston butt, boneless picnic, jowl, and boneless shoulder were greater ($P < 0.01$) in barrows compared with gilts. There was no difference in neck bone weights ($P = 0.18$) or front knee weights ($P = 0.53$) between barrows and gilts. Percent of chilled side weight of the boneless picnic and jowl did not differ between barrows and gilts ($P \geq 0.36$).

***Loin cuts***

There were no interactions for loin cuts expressed either as absolute weights ($P \geq 0.29$) or as a percentage of the chilled side weight ($P \geq 0.13$) between sire line and sex (**Table 3.6**). Both the weight and percent of chilled side weight of the sirloin was greater in the Pietrain sired pigs than the Duroc sired pigs. There were no other differences in overall weight ($P \geq 0.29$) and percent of chilled side weight ($P \geq 0.09$) between the two sire lines. Weight of backribs was greater ($P = 0.01$) in barrows than gilts, but the percent of chilled side weight did not differ ($P = 0.37$) between the two. There were no other differences in overall weights of loin cuts between barrows and gilts ($P \geq 0.11$). Percent of chilled side weight for all other loin cuts was greater ($P < 0.01$) for gilts compared with barrows.

***Carcass cutability***

There was an interaction for bone-in lean cutting yield ($P < 0.001$) as bone-in lean cutting yield of Pietrain sired gilts was 2.1 percentage units greater ($P < 0.001$) than Duroc sired gilts (**Table 3.7**). There was no difference ($P = 0.62$) in bone-in lean cutting yield between Pietrain and Duroc sired barrows. There were no other interactions ($P \geq 0.09$) for cutability between sire line and sex. Overall, bone-in carcass yield and bone-in lean yield were greater ($P \leq 0.01$) in Pietrain sired pigs compared with Duroc sired pigs and were also greater ($P < 0.001$) for gilts compared with barrows. However, boneless carcass cutting yield did not differ ($P \geq 0.14$) between Pietrain and Duroc sired pigs or barrows and gilts.

***Fresh loin quality***

There was an interaction between sire line and sex for early ventral loin pH ($P < 0.01$) and early chop face visual color ($P = 0.02$) (**Table 3.8**). Duroc sired barrows had a greater ($P < 0.001$) early ventral loin pH compared with Pietrain sired barrows. Early ventral loin pH and early chop face visual color did not differ ($P \geq 0.27$) between Pietrain and Duroc sired gilts. There were no other interactions ($P \geq 0.06$) for early loin and chop face quality between sire line and sex. Duroc sired pigs had greater ventral loin visual marbling ($P < 0.01$), chop face visual marbling ($P < 0.001$), chop face subjective firmness ($P < 0.01$), and percent lipid ($P < 0.01$) compared with Pietrain sired pigs. Pietrain sired pigs had a greater ($P = 0.01$) percent moisture than Duroc sired pigs. There were no other differences in visual or subjective evaluations ($P \geq 0.24$) between the two sire lines.  Instrumental color evaluations for L*, a*, and b* did not differ ($P \geq 0.07$) between the two sire lines.  Instrumental color evaluations did not differ ($P \geq 0.22$) between barrows and gilts. Barrows had greater ($P \leq 0.01$) ventral loin visual color scores, ventral loin visual marbling scores, chop face visual marbling scores, and percent lipid compared with gilts. Gilts had greater ($P < 0.001$) percent moisture compared with barrows.

***Aged loin quality***

There was an interaction between sire line and sex for aged ventral loin pH ($P = 0.01$) as Duroc sired barrows had a greater ($P < 0.001$) aged ventral loin pH compared with Pietrain sired barrows (**Table 3.9**). Aged ventral loin pH did not differ ($P = 0.20$) between Pietrain and Duroc sired gilts. There was also an interaction for percent purge loss ($P = 0.03$) between sire line and sex. Percent purge loss was 0.92 percentage units greater ($P = 0.02$) in Pietrain sired barrows than Duroc sired barrows, but did not differ ($P = 0.54$) between Pietrain and Duroc sired gilts. There were no other interactions ($P \geq 0.08$) for aged loin and chop face quality between sire line and sex. Duroc sired pigs had greater ventral visual marbling scores ($P$ = 0.02), ventral pH ($P$ < 0.001), chop visual color scores ($P$ = 0.04), and chop visual marbling scores ($P$ < 0.001). Loin chops from Pietrain sired pigs were more tender ($P$ = 0.01) than loin chops from Duroc sired pigs. No other aged loin and chop quality characteristics differed between Duroc and Pietrain sired pigs ($P \geq 0.06$). Barrows had greater ventral visual marbling scores ($P$ < 0.001), and ventral subjective firmness scores ($P$ < 0.001) compared with Pietrain sired pigs. Loins from barrows also had greater ($P$ = 0.03) ventral Minolta a* values (were less red), greater ($P$ = 0.05) Minolta b* values, and greater ($P$ = 0.02) chroma values (more color saturation) compared with gilts. There were no other differences in aged loin and chop quality characteristics between barrows and gilts ($P$ = 0.07).

***Fresh belly characteristics***

There was and interaction between sire line and sex for belly thickness ($P$ = 0.02) (**Table 3.10**). Duroc sired gilts had thicker bellies ($P$ < 0.001) compared with Pietrain sired gilts however, Pietrain and Duroc sired barrows did not differ ($P$ = 0.48) in belly thickness. There were no other interactions ($P \geq 0.06$) for fresh belly characteristics between sire line and sex. Duroc sired pigs had thicker bellies ($P$ < 0.001) and greater flop distance ($P$ < 0.01) compared with Pietrain sired pigs. Neither belly length nor width differed ($P \geq 0.69$) between the two sire lines. Belly length, thickness, and flop were greater ($P \leq 0.02$) in barrows compared with gilts, but there was no difference ($P$ =0.83) in belly width between the two.

***Belly processing characteristics***

There was an interaction between sire line and sex for bacon slice yield expressed as a percentage of initial (green) weight ($P$ = 0.04) (**Table 3.11**). Pietrain sired gilts had a 3.3 % reduction ($P$ < 0.01) in slice yield compared with Duroc sired gilts. Slice yield did not differ ($P$ =

0.98) between Pietrain and Duroc sired barrows. There were no other interactions ($P \geq 0.08$) for belly processing characteristics between sire line and sex. Duroc sired pigs had a greater cooked yield ($P < 0.01$) and initial (green) slice yield ($P = 0.04$) compared with Pietrain sired pigs. There were no other differences in belly processing characteristics between the two sire lines. Bellies from barrows had greater ($P < 0.001$) initial weights, pump weights, percent pump uptake, cooked weights, and percent cooked yield. There were no differences ($P \geq 0.07$) in initial (green) slice yield, cooked slice yield, and total slice count between barrows and gilts.

***Bacon characteristics and composition***

There was an interaction between sire line and sex for percent lean, percent fat, and lean to fat ratio ($P = 0.04$) (**Table 3.11**). Both percent of bacon lean and lean:fat were greater ($P < 0.001$) in Pietrain sired gilts than barrows, but did not differ ($P \geq 0.44$) between Duroc sired barrows and gilts. Percent of bacon fat was greater ($P < 0.001$) in Pietrain sired barrows than gilts, but did not differ ($P = 0.45$) between Duroc sired barrows and gilts. There were no other interactions in bacon characteristics and composition between sire line and sex ($P \geq 0.06$). Duroc sired pigs had a greater percent of fat ($P = 0.04$) compared with Pietrain sired pigs. Pietrain sired pigs had a greater percent lean ($P = 0.04$) compared with Duroc sired pigs. No other bacon characteristics differed between the two sire lines ($P \geq 0.08$). Average blade slice length, width, and total area was greater ($P < 0.001$) in barrows than gilts. Gilts had a greater ($P = 0.05$) percent lean than barrows, while barrows had a greater ($P = 0.05$) percent fat than gilts. There were no other differences in bacon characteristics between barrows and gilts. Bacon from Pietrain sired pigs had 1.09% more moisture ($P = 0.03$) compared with Duroc sired pigs, while bacon from Duroc sired pigs had 1.37% more extractable lipid ($P = 0.04$) compared with Pietrain sired pigs.

There were no differences in bacon composition (moisture and extractable lipid) between sex (*P* ≥ 0.59).

***Commercial abattoir slaughter and carcass characteristics***

There were no interactions between sire line and sex for any of the carcass characteristics of the pigs slaughtered a commercial abattoir (**Table 3.12**). There was no difference between Pietrain and Duroc sired pigs for HCW (*P* =0.78), carcass yield (*P* = 0.58), $10^{th}$ rib backfat depth (*P* = 0.57, or standardized fat-free lean (*P* = 0.45). Carcasses from barrows were heavier (*P* < 0.001) and fatter (*P* < 0.001) than carcasses from gilts. Carcass yield did not differ (*P* = 0.27) between barrows and gilts however, gilt carcasses had a greater (*P* < 0.001) percent of standardized fat-free lean compared with barrows.

## DISCUSSION

Sex of the pig has a pronounced effect on the composition and quality of pork carcasses and differences in growth and quality traits between barrows and gilts are well documented (Martel et al., 1988; Overholt et al., 2016). Barrows tend to grow and reach physiological maturity at a faster rate than gilts (Lee et al., 2013) however; gilts tend to have a greater feed efficiency than barrows (Latorre et al., 2013). Back fat thickness is greater in barrows and carcasses from barrows are fatter, resulting in a decreased bone-in carcass cutting yield (%), bone-in lean cutting yield (%), and boneless cutting yield (%) when compared with carcasses from gilts (Lee et al., 2013; Boler et al., 2014). Loins from barrows tend to have greater visual marbling and extractable lipid compared with loins from gilts (Nold et al., 1999; Latorre et al., 2003). Differences in carcass characteristics and meat quality between barrows and gilts in this study reflect those of previous research.

As of the end of 2017, the U.S. exported 2.45 million metric tons of pork and pork-related products annually [United States Meat Export Federation (USMEF), 2017], which represents approximately 26% of U.S. pork production (National Pork Board, 2017). Mexico and Japan represent two of the top markets for U.S. pork. Approximately 49% of U.S. pork exports go to Mexico and Japan combined (U.S. Meat Export Federation, 2018). Mexican consumers prefer a lean product and a survey conducted in Mexico, in 2012, identified both color and fat to lean ratio, of fresh pork cuts, as the 2 most important quality traits consumers use to make purchasing decisions (Ngapo et al., 2017). Conversely, Japanese consumers prefer products that are darker in color and more highly marbled (Murphy et al., 2015; Ngapo et al., 2017). The contrasting demands of these two export markets as well as a demand for lean products within the U.S. market have resulted in the need for both lean growth and meat quality production focuses. Duroc-based breeds are often used to supply the needs of a quality-focused market (Japan) because of their meat quality advantages, whereas Pietrain sired pigs are commonly used to satisfy the demand for lean pork in Mexico (NPPC, 1995; Schwab et al., 2006).

Over the years, several studies have investigated the effect of genotype on growth performance, carcass characteristics, carcass yield, and meat quality (Elliset al., 1996; Edwardset al., 2003). Results of this study are similar to those of previous research where the Duroc and Pietrain sired pigs did not differ in overall ADG, ADFI, and G:F. Differences in carcass yield and standardized fat-free lean (%) between Duroc and Pietrain sired pigs were anticipated based on documented genetic differences between the 2 breed types (Edwards et al., 2003; Wood et al., 2004). While previous research (Affentrageret al., 1996; Ellis et al., 1996; Edwards et al., 2003) supports the carcass characteristic and cutability differences observed in the present study, the magnitudes of those differences have decreased. Most likely a result of new breeding objectives and production focuses, and an increased selection for carcass leanness by producers (Schwab et al., 2006). Schwab et al. (2006) determined that, from the mid 1980's to 2006, back fat thickness of purebred Durocs had decreased by 28% while LEA had increased by 17%. Estimates for carcass leanness of Duroc sired pigs from the present study indicate that carcass lean has continued to increase, since the work by Schwab et al. (2006). Back fat decreased an additional 5% and LEA increased an additional 25% in Duroc pigs from the current study compared with those reported by Schwab et al. (2006). In addition, estimated lean percentage of pigs from the current study was 0.62 % greater than pigs from the Schwab et al. (2006) study. It is important to note that the Duroc sired pigs in the present study were not purebred. However, when comparing Duroc sired, crossbred pigs from the present study to Duroc sired, crossbred pigs 15 years ago (Edwards et al., 2003), we see a similar trend as backfat thickness decreased by 25% and LEA increased by 9%. While many studies agree that Pietrain sired pigs are more lean, have a greater percentage of fat-free lean, and have greater overall cutting yields compared with Duroc sired pigs, the magnitude of those differences between the two sire lines were less in this study, compared with previous studies. All pigs in this study shared a common dam line so there is potential that carcass and quality characteristics, unique to each sire line, were muted as a result of using crossbred pigs instead of purebred. Another explanation for the reduced magnitude of difference between the 2 groups could be that breeding objectives have changed both the lean growth ability of the Duroc, as well as improved the fat quality of the Pietrain, evidenced by the notably small differences between the Pietrain and Duroc sired pigs. Even though the differences between the 2 sire lines were not as great as we anticipated, there were still significant differences in carcass yield, percent lean, and meat quality. Because Pietrain sired pigs are considered lean, fast-growing pigs compared with Duroc sired pigs (Schwab et al., 2006), it was expected that carcass yield and percent lean would be greater in the Pietrain sired pigs. Just as Pietrain sired pigs are used to satisfy the demands of a lean-focused market, Duroc sired pigs are used for their meat quality advantages (Schwab et al., 2006). In this study, Duroc sired pigs produced loins that were visually darker and more highly marbled, with a greater ultimate pH; all traits that are indicative of a high quality product (Edwards et al., 2003; Murphy, 2015). While fresh color and marbling are used by consumers as indicators of tenderness and juiciness (Wood et al., 2004; Lonergan et al., 2007) there is no one, single quality trait that independently influences overall eating quality (Wilson et al., 2017). However, even though color and marbling are not always indicative of eating experience, these traits remain as essential breeding objectives when one considers the value consumers place on them (Ngapo et al., 2007). These quality traits become even more significant when catering to our export markets as both Mexico and Japan rank color and fat to lean ratio within their top three most important quality traits used when making purchasing decisions (Ngapo et al., 2007; Ngapo et al., 2017). In terms of marbling, products from both the Pietrain and Duroc sired pigs, in this study, would satisfy the expectations of both Mexican and Japanese consumers as both consider marbling scores of 2-3 acceptable (Ngapo et al., 2012; Ngapo et al., 2017). Small differences in fat quality between the Pietrain and Duroc sired pigs support the hypothesis that new breeding objectives have actually minimized heterogeneity between sire lines. However, differences in color quality are still important to consider as Mexican consumers associate a darker color with previously frozen, undesirable pork (Ngapo et al., 2017) and Japanese consumers associate a dark color with high quality pork (Ngapo et al., 2007). Therefore, Duroc sired pigs would not meet Mexican consumer expectations, in terms of color.

While new breeding objectives have certainly met the consumer expectations of a quality-focused market though improvements in both color and marbling, belly quality has been negatively affected trying to meet the goals of a lean-focused market (Correa et al., 2008). Fat tissue growth has been substantially reduced as a result of selection for improved lean efficiency (Schinckel et al., 2002). Selection for increased growth rates result in softer, thinner bellies (Correa et al., 2008), and quality defects, such as belly thickness, often result in a substantial decrease in profitability (Person et al., 2005). Processing characteristics like slice integrity, slice yield, and percent retail acceptable bacon slices are negatively correlated with bellies that are more lean (Brewer et al., 1995; Person et al., 2005). Recent estimates reported that sliced bacon was the most valuable retail pork cut (U.S. Bureau of Labor Statistics, 2018) and Overholt et al. (2016) reported that bellies from a quality production focus may be better suited for commercial bacon production. In the current study, it was expected that bellies from the Pietrain sired pigs would have more lean and poor slicing characteristics compared with the bellies from the Duroc sired pigs. Indeed, fresh bellies from Pietrain sired pigs were not as thick as those from Duroc sired pigs however, the magnitude of difference between the two sire lines was only 0.2 cm or a difference of 0.05%. Interestingly, there were very few differences in belly processing characteristics between Pietrain and Duroc sired pigs. Durocs had a greater percent of cooked yield and initial slice yield, but the 2 sire lines did not differ in percent cooked slice yield or total number of slices. Differences in lean between sire lines were more evident when it came to bacon slice characteristics as bacon slices from Pietrain sired pigs had a greater percent of lean and a greater lean to fat ratio, while bacon slices from Duroc sired pigs had a greater percent of fat. Bacon from Pietrain sired pigs also had a greater percent of moisture than Duroc sired pigs, which also indicates a difference in lean between the two sire lines. Based on the differences in bacon slice characteristics, it was expected that bacon from Duroc sired pigs would have a greater percent of extractable lipid, and they did. However, the magnitude of difference between the two sire lines was less than expected at a difference of 1.37 %. Bellies from Pietrain sired pigs had numerically greater percent of pump uptake (0.61%) which may have caused the increase in percent moisture. Again, it is possible that these minimal differences between the 2 sire lines is a direct result of the two sharing a common dam line and therefore, differences in and variability between belly and bacon characteristics were reduced. The lack of differences in belly characteristics may also be related to increases in the average ELW and HCW. Over the last 20 years, pork carcasses have increased from 86 kg to 96 kg (NASS, 2018) and for every 10 kg increase in weight, there is a 0.83% increase in belly yields or a 0.083% increase per 1 kg (Cisneros et al., 1996). In the study by Cisneros et al. (1996), ELW was 127 kg and bellies weighed approximately 7.60 kg, which means that at an ELW of 137 kg, average belly weight should be 7.66 kg. Pigs in the current study were only 4 kg heavier than those in the Cisneros et al. (1996) study however, using 0.083 % per 1 kg increase, we can estimate a 7.63 kg belly; actual average belly weight in this study was 7.62 kg. The magnitude of difference between belly weights of the two sire lines has also changed over the last 15 years from a 7.7% difference to a 0.78% difference (Edwards et al., 2003). Processing yield is positively correlated with belly thickness (Person et al., 2005), so both an increase in HCW and a decrease in the magnitude of difference in belly weight may have also alleviated some of the processing differences between the 2 sire lines.

There were a few interactions between sire line and sex however, these interactions do not negate that fact that Pietrain sired pigs were more lean than Duroc sired pigs, and that Duroc sired pigs produced a loin that was darker and more highly marbled. Regardless of the interactions, many of the results of this study were characteristic of what would be expected from a lean production focus line (Pietrain) and quality production focus line (Duroc).

By controlling both inherent and environmental factors it was determined that there are specific effects of breed type (lean vs. quality) on growth performance, carcass characteristics, fresh belly characteristics, and commercial bacon slicing yields and characteristics. While differences between these 2 breed types have been documented, this present study provides a better understanding of differences between today's lean growth production focus and meat quality production focus. Fewer differences in overall meat quality were observed than was expected based on historical information. Further, the magnitude of difference of some traits were less than anticipated. This may be explained in part by all pigs sharing the same dam line. It may also be a result of genetic improvement of both sire lines. The Pietrain pigs were not as extreme in their leanness estimates as historically reported and the Duroc pigs performed better during the live phase portion of the experiment than historically anticipated. Based on the results of this study, Pietrain sired pigs are suitable to satisfy the demand of a lean-focused market (Mexico) and Duroc sired pigs are suitable to supply the needs of a quality-focused market (Japan).

## TABLES

**Table 3.1.** Growth performance of barrows and gilts from either Pietrain or Duroc sired pigs

| | Sire line | | Sex | | | *P*-values | | |
|---|---|---|---|---|---|---|---|---|
| Item | Pietrain | Duroc | Barrows | Gilts | SEM | Sire Line | Sex | Sire line × Sex |
| Pens, n | 40 | 40 | 40 | 40 | | | | |
| Birth wt, kg | 1.50 | 1.51 | 1.55 | 1.46 | 0.04 | 0.70 | 0.02 | 0.11 |
| Weaning wt, kg | 5.77 | 6.40 | 6.11 | 6.05 | 0.27 | < 0.001 | 0.53 | 0.94 |
| Phase 1 (d0-35)[1] | | | | | | | | |
| BW d0, kg | 28.07 | 28.07 | 28.05 | 28.08 | 0.14 | 0.98 | 0.85 | 0.36 |
| ADG, kg/d | 0.97 | 0.96 | 1.00 | 0.93 | 0.01 | 0.73 | < 0.001 | 0.84 |
| ADFI, kg/d | 1.99 | 2.07 | 2.10 | 1.96 | 0.04 | 0.02 | < 0.001 | 0.21 |
| Cost/kg gain, $ | 0.56 | 0.59 | 0.57 | 0.58 | 0.01 | < 0.001 | 0.40 | 0.12 |
| G:F | 0.49 | 0.47 | 0.48 | 0.48 | 0.00 | < 0.001 | 0.53 | 0.15 |
| BW d35, kg | 62.04 | 61.78 | 63.20 | 60.62 | 0.37 | 0.63 | < 0.001 | 0.78 |
| Phase 2 (d36-70) | | | | | | | | |
| ADG, kg/d | 1.05 | 1.03 | 1.11 | 0.97 | 0.03 | 0.60 | < 0.001 | 0.23 |
| ADFI, kg/d | 3.15 | 3.23 | 3.39 | 2.99 | 0.20 | 0.09 | < 0.001 | 0.83 |
| Cost/kg gain, $ | 0.73 | 0.76 | 0.75 | 0.74 | 0.02 | 0.18 | 0.91 | 0.36 |
| G:F | 0.33 | 0.32 | 0.33 | 0.33 | 0.03 | 0.56 | 0.85 | 0.90 |
| BW d70, kg | 98.52 | 97.80 | 101.76 | 94.56 | 0.93 | 0.43 | < 0.001 | 0.19 |
| Phase 3 (d71-98) | | | | | | | | |
| ADG, kg/d | 1.13 | 1.15 | 1.16 | 1.12 | 0.03 | 0.51 | 0.29 | 0.87 |
| ADFI, kg/d | 3.41 | 3.62 | 3.71 | 3.31 | 0.08 | < 0.01 | < 0.001 | 0.35 |
| Cost/kg gain, $ | 0.75 | 0.77 | 0.80 | 0.72 | 0.04 | 0.61 | < 0.01 | 0.84 |
| G:F | 0.33 | 0.36 | 0.31 | 0.38 | 0.03 | 0.48 | 0.10 | 0.40 |
| BW d98, kg | 130.17 | 129.65 | 134.17 | 125.65 | 0.72 | 0.62 | < 0.001 | 0.33 |
| Overall (d0-98) | | | | | | | | |

**Table 3.1. (cont)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ADG, kg/d | 1.03 | 1.04 | 1.08 | 0.99 | 0.01 | 0.96 | < 0.001 | 0.93 |
| ADFI, kg/d | 2.80 | 2.87 | 3.03 | 2.65 | 0.03 | 0.08 | < 0.001 | 0.11 |
| Cost/kg gain, $ | 0.69 | 0.7 | 0.71 | 0.68 | 0.01 | 0.04 | < 0.01 | 0.19 |
| G:F | 0.37 | 0.36 | 0.36 | 0.38 | 0.00 | 0.09 | < 0.001 | 0.01 |

[1]Pigs were approximately 10 wks old on d 0.

**Table 3.2.** Carcass characteristics of barrows and gilts from either Pietrain or Duroc sired pigs slaughtered under university conditions[1]

| | Sire Line | | Sex | | | *P*-value | | |
|---|---|---|---|---|---|---|---|---|
| Item | Pietrain | Duroc | Barrow | Gilt | SEM | Sire line | Sex | Sire line × Sex |
| Pens, n | 40 | 40 | 40 | 40 | | | | |
| Ending live weight, kg | 131.05 | 130.69 | 135.40 | 126.34 | 1.01 | 0.72 | < 0.001 | 0.32 |
| HCW, kg | 103.07 | 103.66 | 107.16 | 99.57 | 0.87 | 0.50 | < 0.001 | 0.36 |
| Carcass yield, % | 78.82 | 79.31 | 79.34 | 78.79 | 0.16 | < 0.01 | < 0.001 | 0.14 |
| Loin muscle area, $cm^2$ | 55.58 | 55.40 | 55.45 | 55.52 | 0.96 | 0.85 | 0.94 | 0.76 |
| 10th rib back fat depth, cm | 1.60 | 1.92 | 1.93 | 1.59 | 0.07 | < 0.001 | < 0.001 | 0.13 |
| Standardized fat-free lean, %[2] | 55.71 | 54.39 | 54.07 | 56.03 | 0.42 | < 0.01 | < 0.001 | 0.21 |

[1]Values based on data collected from heaviest and third heaviest in each pen (160 total pigs)

[2]Standardized fat-free lean = ((8.588 + (0.465 × HCW, lb) – (21.896 × fat depth, in) + (3.005 × LTL area, $in^2$))/HCW) × 100, (Burson and Berg, 2001).

**Table 3.3.** Characteristics of whole and trimmed primal cuts of barrows and gilts from either Pietrain of Duroc sired pigs

| | Sire Line | | Sex | | | *P-value* | | |
|---|---|---|---|---|---|---|---|---|
| Item | Pietrain | Duroc | Barrow | Gilt | SEM | Sire Line | Sex | Sire line × Sex |
| Pens, n | 40 | 40 | 40 | 40 | | | | |
| Chilled side wt, kg | 51.42 | 51.69 | 53.53 | 49.58 | 0.32 | 0.55 | < 0.001 | 0.30 |
| Whole shoulder, kg | 10.93 | 11.05 | 11.40 | 10.58 | 0.19 | 0.27 | < 0.001 | 0.33 |
| % chilled side wt | 21.27 | 21.35 | 21.27 | 21.36 | 0.33 | 0.53 | 0.49 | 0.01 |
| Bone-in Boston, kg | 4.33 | 4.24 | 4.38 | 4.20 | 0.07 | 0.09 | < 0.01 | 0.11 |
| % chilled side wt | 8.44 | 8.20 | 8.16 | 8.48 | 0.12 | < 0.01 | < 0.001 | < 0.01 |
| Bone-in picnic, kg | 4.59 | 4.59 | 4.76 | 4.42 | 0.05 | 0.93 | < 0.001 | 0.68 |
| % chilled side wt | 8.94 | 8.86 | 8.88 | 8.92 | 0.07 | 0.42 | 0.65 | 0.19 |
| Whole loin, kg | 13.94 | 14.09 | 14.65 | 13.38 | 0.12 | 0.35 | < 0.001 | 0.06 |
| % chilled side wt | 27.05 | 27.24 | 27.34 | 26.94 | 0.16 | 0.23 | 0.02 | 0.02 |
| Trimmed loin, kg | 11.46 | 11.16 | 11.69 | 10.93 | 0.13 | 0.12 | < 0.001 | 0.93 |
| % chilled side wt | 22.27 | 21.59 | 21.81 | 22.05 | 0.22 | 0.02 | 0.41 | 0.43 |
| Whole ham, kg | 11.75 | 11.71 | 12.02 | 11.44 | 0.08 | 0.76 | < 0.001 | 0.91 |
| % chilled side wt | 22.87 | 22.65 | 22.42 | 23.10 | 0.10 | 0.09 | < 0.001 | 0.28 |
| Trimmed ham, kg | 9.29 | 9.24 | 9.37 | 9.15 | 0.08 | 0.70 | 0.07 | 0.40 |
| % chilled side wt | 18.10 | 17.87 | 17.49 | 18.48 | 0.14 | 0.22 | < 0.001 | 0.08 |
| Natural fall belly, kg | 7.59 | 7.65 | 7.93 | 7.31 | 0.13 | 0.59 | < 0.001 | 0.09 |
| % chilled side wt | 14.75 | 14.77 | 14.79 | 14.73 | 0.23 | 0.89 | 0.69 | 0.11 |
| Spareribs, kg | 1.84 | 1.85 | 1.89 | 1.80 | 0.02 | 0.67 | < 0.001 | 0.06 |
| % chilled side wt | 3.59 | 3.58 | 3.53 | 3.64 | 0.05 | 0.78 | 0.01 | 0.01 |

**Table 3.4.** Characteristics of ham carcass cuts of barrows and gilts from either Pietrain or Duroc sired pigs

| | Sire Line | | Sex | | | *P-value* | | |
|---|---|---|---|---|---|---|---|---|
| Item | Pietrain | Duroc | Barrow | Gilt | SEM | Sire Line | Sex | Sire line × Sex |
| Pens, n | 40 | 40 | 40 | 40 | | | | |
| Inside ham, kg | 1.87 | 1.83 | 1.86 | 1.84 | 0.02 | 0.11 | 0.61 | 0.94 |
| % chilled side wt | 3.65 | 3.54 | 3.46 | 3.72 | 0.03 | 0.02 | < 0.001 | 0.51 |
| Outside ham, kg | 2.71 | 2.70 | 2.74 | 2.67 | 0.03 | 0.83 | 0.09 | 0.60 |
| % chilled side wt | 5.27 | 5.23 | 5.12 | 5.39 | 0.05 | 0.41 | < 0.001 | 0.96 |
| Knuckle, kg | 1.52 | 1.44 | 1.48 | 1.48 | 0.02 | < 0.001 | 0.73 | 0.30 |
| % chilled side wt | 2.97 | 2.78 | 2.77 | 2.99 | 0.03 | < 0.001 | < 0.001 | 0.09 |
| Inner shank, kg | 0.67 | 0.68 | 0.70 | 0.66 | 0.01 | 0.31 | < 0.01 | 0.33 |
| % chilled side wt | 1.30 | 1.32 | 1.30 | 1.32 | 0.02 | 0.59 | 0.26 | 0.12 |
| Lite butt, kg | 0.23 | 0.24 | 0.24 | 0.24 | 0.01 | 0.30 | 0.65 | 0.54 |
| % chilled side wt | 0.45 | 0.47 | 0.44 | 0.48 | 0.01 | 0.31 | 0.02 | 0.65 |
| Boneless ham, kg[1] | 6.87 | 6.88 | 6.96 | 6.79 | 0.07 | 0.92 | 0.11 | 0.37 |
| % chilled side wt | 13.52 | 13.43 | 13.51 | 13.43 | 0.11 | 0.56 | 0.58 | 0.32 |

[1]Boneless ham = inside ham (NAMP #402F), kg + outside ham (NAMP #402E), kg + knuckle (NAMP #402H), kg + inner shank, kg + lite butt, kg.

**Table 3.5.** Characteristics of shoulder carcass cuts of barrows and gilts from either Pietrain or Duroc sired pigs

| | Sire Line | | Sex | | | *P-value* | | |
|---|---|---|---|---|---|---|---|---|
| Item | Pietrain | Duroc | Barrow | Gilt | SEM | Sire Line | Sex | Sire line × Sex |
| Pens, n | 40 | 40 | 40 | 40 | | | | |
| Boneless Boston, kg | 4.02 | 3.89 | 4.05 | 3.86 | 0.07 | 0.02 | < 0.001 | 0.09 |
| % chilled side wt | 7.83 | 7.51 | 7.54 | 7.80 | 0.14 | < 0.001 | < 0.01 | < 0.01 |
| Boneless Picnic, kg | 3.85 | 3.86 | 3.98 | 3.72 | 0.04 | 0.81 | < 0.001 | 0.48 |
| % chilled side wt | 7.49 | 7.46 | 7.44 | 7.51 | 0.06 | 0.72 | 0.36 | 0.09 |
| Neckbones, kg | 1.27 | 1.30 | 1.30 | 1.26 | 0.04 | 0.29 | 0.18 | 0.44 |
| % chilled side wt | 2.48 | 2.51 | 2.43 | 2.55 | 0.07 | 0.60 | 0.02 | 0.27 |
| Jowl, kg | 1.53 | 1.49 | 1.57 | 1.44 | 0.02 | 0.13 | < 0.001 | 0.04 |
| % chilled side wt | 2.97 | 2.87 | 2.93 | 2.91 | 0.03 | 0.06 | 0.61 | 0.13 |
| Front knee, kg | 0.56 | 0.61 | 0.59 | 0.58 | 0.03 | 0.01 | 0.53 | 0.78 |
| % chilled side wt | 1.10 | 1.17 | 1.10 | 1.17 | 0.06 | 0.03 | 0.09 | 0.63 |
| Boneless shoulder, kg[1] | 7.86 | 7.75 | 8.03 | 7.58 | 0.10 | 0.19 | < 0.001 | 0.16 |
| % chilled side wt | 15.32 | 14.98 | 14.98 | 15.31 | 0.17 | < 0.01 | < 0.01 | < 0.01 |

[1]Boneless shoulder = boneless Boston butt (NAMP # 406A), kg + boneless picnic (NAMP #405A), kg.

**Table 3.6.** Characteristics of loin carcass cuts of barrows and gilts from either Pietrain or Duroc sired pigs

| | Sire Line | | Sex | | | *P-value* | | |
|---|---|---|---|---|---|---|---|---|
| Item | Pietrain | Duroc | Barrow | Gilt | SEM | Sire Line | Sex | Sire line × Sex |
| Pens, n | 40 | 40 | 40 | 40 | | | | |
| Canadian Back, kg | 3.86 | 3.87 | 3.91 | 3.82 | 0.04 | 0.91 | 0.11 | 0.54 |
| % chilled side wt | 7.52 | 7.49 | 7.30 | 7.71 | 0.07 | 0.77 | < 0.001 | 0.96 |
| Tenderloin, kg | 0.55 | 0.54 | 0.54 | 0.55 | 0.02 | 0.45 | 0.37 | 0.77 |
| % chilled side wt | 1.06 | 1.04 | 1.00 | 1.10 | 0.03 | 0.27 | < 0.001 | 0.90 |
| Sirloin, kg | 1.02 | 0.96 | 1.00 | 0.99 | 0.02 | < 0.01 | 0.68 | 0.29 |
| % chilled side wt | 2.00 | 1.86 | 1.86 | 2.00 | 0.04 | < 0.01 | < 0.01 | 0.13 |
| Backribs, kg | 0.81 | 0.81 | 0.84 | 0.79 | 0.02 | 0.97 | 0.01 | 0.76 |
| % chilled side wt | 1.58 | 1.58 | 1.57 | 1.59 | 0.03 | 0.97 | 0.37 | 0.30 |
| Backbone, kg | 2.0 | 2.06 | 2.11 | 2.05 | 0.04 | 0.29 | 0.11 | 0.84 |
| % chilled side wt | 4.09 | 3.98 | 3.94 | 4.13 | 0.05 | 0.12 | 0.01 | 0.38 |
| Boneless loin, kg[1] | 5.43 | 5.36 | 5.44 | 5.35 | 0.05 | 0.36 | 0.22 | 0.82 |
| % chilled side wt | 10.58 | 10.39 | 10.16 | 10.81 | 0.10 | 0.09 | < 0.001 | 0.62 |

[1]Boneless loin = Canadian back loin (NAMP #414), kg + tenderloin (NAMP #415A), kg + sirloin (NAMP #413D), kg.

**Table 3.7.** Carcass cutability characteristics of barrows and gilts from either Pietrain or Duroc sired pigs

| | Sire Line | | Sex | | | *P-value* | | |
|---|---|---|---|---|---|---|---|---|
| Item | Pietrain | Duroc | Barrow | Gilt | SEM | Sire Line | Sex | Sire line × Sex |
| Pens, n | 40 | 40 | 40 | 40 | | | | |
| Bone-in carcass cutting yield, %[1] | 72.52 | 71.30 | 71.14 | 72.68 | 0.39 | < 0.01 | < 0.001 | 0.09 |
| Bone-in lean cutting yield, %[2] | 57.74 | 56.52 | 56.34 | 57.92 | 0.30 | 0.01 | < 0.001 | 0.04 |
| Boneless carcass cutting yield, %[3] | 54.04 | 53.46 | 53.83 | 53.68 | 0.28 | 0.14 | 0.70 | 0.56 |

[1] Bone-in carcass cutting yield = [(trimmed ham, kg + bone-in Boston, kg + bone-in picnic, kg + trimmed loin, kg + natural fall belly, kg) / left side chilled weight, kg] × 100.

[2] Bone-in lean cutting yield = [(trimmed ham, kg + bone-in Boston + bone-in picnic + trimmed loin) ÷ left side chilled weight] × 100.

[3] Boneless carcass cutting yield = [((inside ham, kg + outside ham, kg + knuckle, kg + inner shank, kg + lite butt, kg) + (Canadian back loin, kg +tenderloin, kg + sirloin, kg) + (boneless Boston, kg + boneless picnic, kg) + (belly, kg)) / left side chilled weight] × 100.

**Table 3.8.** Early loin and chop face quality and color of barrows and gilts from either Pietrain or Duroc sired pigs[1]

| | Sire Line | | Sex | | | *P-value* | | |
|---|---|---|---|---|---|---|---|---|
| Item | Pietrain | Duroc | Barrow | Gilt | SEM | Sire line | Sex | Sire line x Sex |
| Pens, n | 40 | 40 | 40 | 40 | | | | |
| *Loin* | | | | | | | | |
| Visual color[2] | 3.43 | 3.44 | 3.53 | 3.34 | 0.09 | 0.87 | 0.02 | 0.33 |
| Visual marbling[3] | 1.76 | 2.15 | 2.10 | 1.81 | 0.12 | < 0.01 | 0.01 | 0.56 |
| Subjective firmness[4] | 3.64 | 3.56 | 3.64 | 3.57 | 0.07 | 0.24 | 0.32 | 0.13 |
| Lightness, L*[5] | 48.33 | 48.09 | 48.44 | 47.99 | 1.17 | 0.56 | 0.29 | 0.06 |
| Redness, a*[6] | 10.10 | 10.01 | 10.10 | 10.00 | 0.83 | 0.70 | 0.68 | 0.96 |
| Yellowness, b*[7] | 3.52 | 3.13 | 3.43 | 3.22 | 0.66 | 0.09 | 0.35 | 0.56 |
| Ventral pH | 5.53 | 5.57 | 5.57 | 5.53 | 0.01 | < 0.001 | < 0.01 | < 0.01 |
| *Chop* | | | | | | | | |
| Visual color | 3.16 | 3.21 | 3.19 | 3.18 | 0.06 | 0.37 | 0.82 | 0.02 |
| Visual marbling | 2.12 | 2.71 | 2.62 | 2.21 | 0.13 | < 0.001 | < 0.01 | 0.84 |
| Subjective firmness | 3.09 | 3.25 | 3.18 | 3.16 | 0.05 | < 0.01 | 0.81 | 0.24 |
| Lightness, L* | 50.07 | 49.56 | 50.16 | 49.47 | 1.19 | 0.37 | 0.22 | 0.15 |
| Redness, a* | 9.75 | 9.43 | 9.73 | 9.45 | 0.25 | 0.21 | 0.27 | 0.92 |
| Yellowness, b* | 3.47 | 3.02 | 3.37 | 3.12 | 0.27 | 0.07 | 0.31 | 0.99 |
| Moisture, % | 73.04 | 72.65 | 72.56 | 73.13 | 0.26 | 0.01 | < 0.001 | 0.47 |
| Extractable lipid, % | 3.14 | 3.56 | 3.70 | 3.01 | 0.21 | < 0.01 | < 0.001 | 0.26 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]NPPC color based on the 1999 standards measured in half point increments where 1 = palest, 6 = darkest.

[3]NPPC marbling based on the 1999 standards measured in half point increments where 1 = least amount of marbling, 6 = greatest amount of marbling

[4]NPPC firmness based on the 1991 scale measured in half point increments where 1 = softest, 5 = firmest

[5]L* measures darkness (0) to lightness (100; greater L* indicates a lighter color).

[6]a* measures redness (greater a* indicates a redder color).

[7]b* measures yellowness (greater b* indicates a more yellow color).

**Table 3.9.** Aged loin and chop quality of barrows and gilts from either Pietrain or Duroc sired pigs[1]

| | Sire Line | | Sex | | | *P-value* | | |
|---|---|---|---|---|---|---|---|---|
| Aged postmortem variable | Pietrain | Duroc | Barrow | Gilt | SEM | Sire line | Sex | Sire line x Sex |
| *Loin* | | | | | | | | |
| Visual color[2] | 3.29 | 3.42 | 3.42 | 3.29 | 0.10 | 0.08 | 0.08 | 0.21 |
| Visual marbling[3] | 2.16 | 2.39 | 2.48 | 2.08 | 0.24 | 0.02 | < 0.001 | 0.90 |
| Subjective firmness[4] | 3.70 | 3.71 | 3.80 | 3.60 | 0.05 | 0.80 | < 0.001 | 0.61 |
| Lightness, L*[5] | 50.19 | 49.16 | 50.14 | 49.67 | 0.41 | 0.17 | 0.26 | 0.08 |
| Redness, a*[6] | 10.49 | 10.61 | 10.80 | 10.31 | 0.24 | 0.59 | 0.03 | 0.90 |
| Yellowness, b*[7] | 5.09 | 4.80 | 5.17 | 4.72 | 0.23 | 0.18 | 0.05 | 0.16 |
| Ventral pH | 5.58 | 5.63 | 5.61 | 5.60 | 0.04 | < 0.001 | 0.12 | 0.01 |
| Early hue angle, º[8] | 18.68 | 16.98 | 18.37 | 17.29 | 2.02 | 0.07 | 0.24 | 0.65 |
| Early chroma[9] | 10.74 | 10.55 | 10.73 | 10.56 | 0.97 | 0.51 | 0.53 | 0.87 |
| Aged hue angle, º | 25.71 | 24.20 | 25.49 | 24.42 | 0.88 | 0.07 | 0.19 | 0.10 |
| Aged chroma | 11.71 | 11.71 | 12.02 | 11.39 | 0.18 | 0.99 | 0.02 | 0.64 |
| Purge loss, %[10] | 7.31 | 6.97 | 7.01 | 7.27 | 0.26 | 0.19 | 0.32 | 0.03 |
| *Chop* | | | | | | | | |
| Visual color | 3.21 | 3.32 | 3.29 | 3.24 | 0.05 | 0.04 | 0.39 | 0.39 |
| Visual marbling | 2.04 | 2.68 | 2.58 | 2.13 | 0.17 | < 0.001 | < 0.001 | 0.38 |
| Subjective firmness | 3.08 | 3.15 | 3.10 | 3.13 | 0.13 | 0.21 | 0.56 | 0.30 |
| Lightness, L* | 52.22 | 51.76 | 51.85 | 52.14 | 0.51 | 0.38 | 0.57 | 0.23 |
| Redness, a* | 9.90 | 10.05 | 10.15 | 9.80 | 0.19 | 0.42 | 0.07 | 0.78 |
| Yellowness, b* | 4.50 | 4.43 | 4.59 | 4.34 | 0.29 | 0.75 | 0.27 | 0.86 |
| Hue angle, º | 24.22 | 23.57 | 24.20 | 23.60 | 0.96 | 0.44 | 0.47 | 0.94 |
| Chroma | 10.92 | 11.04 | 11.18 | 10.78 | 0.20 | 0.62 | 0.10 | 0.75 |
| Warner-Bratzler shear force, kg[11] | 2.25 | 2.40 | 2.29 | 2.35 | 0.04 | 0.02 | 0.30 | 0.74 |
| Cook loss, % | 20.08 | 20.73 | 20.17 | 20.64 | 0.34 | 0.06 | 0.16 | 0.83 |

**Table 3.9. (cont)**

[1]Aged postmortem traits were evaluated 14 d postmortem

[2]NPPC color based on the 1999 standards measured in half point increments where 1 = palest, 6 = darkest.

[3]NPPC marbling based on the 1999 standards measured in half point increments where 1 = least amount of marbling, 6 = greatest amount of marbling

[4]NPPC firmness based on the 1991 scale measured in half point increments where 1 = softest, 5 = firmest

[5]L* measures darkness to lightness (greater L* indicates a lighter color).

[6]a* measures redness (greater a* indicates a redder color).

[7]b* measures yellowness (greater b* indicates a more yellow color).

[8]Hue angle =IF(OR(a*="",b*="")=TRUE,"",IF(ATAN2(a*,b*)<0,360+ATAN2(a*,b*)*180/PI(),

[9]Chroma = sqrt[(a*, redness^2)+(b*, yellowness^2)]

[10]Purge loss = [(1 d weight, kg – 14 d weight, kg) / 1 d weight, kg] ×100

[11]Includes Warner-Bratzler shear force evaluated on chops cooked to 63° C

**Table 3.10.** Fresh belly characteristics of barrows and gilts from either Pietrain or Duroc sired pigs

| | Sire Line | | Sex | | | *P-value* | | |
|---|---|---|---|---|---|---|---|---|
| Item | Pietrain | Duroc | Barrow | Gilt | SEM | Sire line | Sex | Sire line x Sex |
| Pens, n | 40 | 40 | 40 | 40 | | | | |
| Length, cm | 71.05 | 71.11 | 71.74 | 70.42 | 0.49 | 0.88 | < 0.001 | 0.70 |
| Width, cm | 28.21 | 28.19 | 28.19 | 28.14 | 0.25 | 0.69 | 0.83 | 0.54 |
| Thickness, cm[1] | 3.97 | 4.17 | 4.27 | 3.87 | 0.06 | < 0.001 | < 0.001 | 0.02 |
| Flop, cm | 19.18 | 22.23 | 21.90 | 19.50 | 0.98 | < 0.01 | 0.02 | 0.06 |

[1]Thickness was an average of measurements from 8 locations from the anterior to posterior, with 4 measurements on each of the dorsal and ventral edges, respectively.

**Table 3.11.** Belly processing and bacon slice characteristics of barrows and gilts from either Pietrain or Duroc sired pigs

| | Sire Line | | Sex | | | *P*-value | | |
|---|---|---|---|---|---|---|---|---|
| Item | Pietrain | Duroc | Barrow | Gilt | SEM | Sire line | Sex | Sire line × Sex |
| Pens, n | 40 | 40 | 40 | 40 | | | | |
| Initial weight, kg | 6.47 | 6.58 | 6.85 | 6.20 | 0.11 | 0.25 | < 0.001 | 0.18 |
| Pump weight, kg | 7.31 | 7.48 | 7.79 | 7.00 | 0.14 | 0.16 | < 0.001 | 0.28 |
| Pump uptake, % | 12.97 | 13.58 | 13.87 | 12.69 | 0.39 | 0.10 | < 0.01 | 0.89 |
| Cooked weight, kg | 6.69 | 6.89 | 7.19 | 6.39 | 0.12 | 0.09 | < 0.001 | 0.17 |
| Cooked yield, % | 103.33 | 104.51 | 104.96 | 102.87 | 0.39 | < 0.01 | < 0.001 | 0.32 |
| Slice yield (initial wt), %[1] | 90.86 | 92.51 | 92.41 | 90.96 | 1.19 | 0.04 | 0.07 | 0.04 |
| Slice yield (cooked wt), %[2] | 87.92 | 88.54 | 88.04 | 88.41 | 1.10 | 0.37 | 0.59 | 0.08 |
| Slice count, # | 127.00 | 126.00 | 127.00 | 127.00 | 2.30 | 0.49 | 0.95 | 0.12 |
| Bacon slice image analysis[3] | | | | | | | | |
| Average slice length, cm | 25.33 | 25.21 | 25.30 | 25.24 | 0.11 | 0.46 | 0.71 | 0.15 |
| Average slice width, cm | 3.69 | 3.83 | 3.79 | 3.73 | 0.08 | 0.21 | 0.55 | 0.21 |
| Average slice area, $cm^2$ | 37.49 | 38.25 | 38.98 | 36.76 | 0.42 | 0.21 | < 0.001 | 0.15 |
| Average lean area, $cm^2$ | 14.51 | 14.23 | 14.56 | 14.18 | 0.20 | 0.33 | 0.20 | 0.39 |
| Average secondary lean area, $cm^2$ | 4.20 | 4.25 | 4.29 | 4.15 | 0.10 | 0.73 | 0.31 | 0.21 |
| Average slice lean, % | 50.06 | 48.48 | 48.50 | 50.04 | 0.54 | 0.04 | 0.05 | < 0.01 |
| Average slice fat, % | 49.94 | 51.52 | 51.50 | 49.96 | 0.54 | 0.04 | 0.05 | < 0.01 |
| Lean:fat | 1.02 | 0.96 | 0.96 | 1.02 | 0.02 | 0.04 | 0.04 | < 0.01 |
| Bacon composition | | | | | | | | |
| Moisture, % | 49.94 | 48.85 | 49.26 | 49.53 | 0.35 | 0.03 | 0.59 | 0.16 |
| Fat, % | 33.99 | 35.36 | 34.84 | 34.51 | 0.46 | 0.04 | 0.61 | 0.36 |

[1]Slice yield (initial wt) = (sliced weight / initial weight) × 100.

[2]Slice yield (cooked wt) = (sliced weight / cooked weight) × 100.

[3]Bacon slice image analysis was the mean of the image analyses evaluated on blade end, middle, and flank end slices.

**Table 3.12.** Carcass characteristics of barrows and gilts from either Pietrain or Duroc sired pigs slaughtered under federally inspected, commercial conditions

| | Sire Line | | Sex | | | *P*-value | | |
|---|---|---|---|---|---|---|---|---|
| Item[1] | Pietrain | Duroc | Barrow | Gilt | SEM | Sire line | Sex | Sire line × Sex |
| Pens, n | 40 | 40 | 40 | 40 | | | | |
| HCW, kg | 95.20 | 95.51 | 98.14 | 92.57 | 1.07 | 0.78 | < 0.001 | 0.23 |
| Carcass yield, % | 75.46 | 75.69 | 75.35 | 75.80 | 0.41 | 0.58 | 0.27 | 0.07 |
| 10th rib back fat depth, cm | 2.46 | 2.51 | 2.71 | 2.26 | 0.08 | 0.57 | < 0.001 | 0.23 |
| Standardized fat-free lean, %[2] | 51.84 | 51.59 | 50.78 | 52.66 | 0.33 | 0.45 | < 0.001 | 0.23 |

[1]Values based on data collected from second heavies and lightest pig in each pen (160 total pigs)

[2]Standardized fat-free lean = ((23.568 + (0.503 × HCW, lb) – (21.348 × fat thickness, in))/HCW) × 100, (Burson and Berg, 2001).

**Table 3.13.** Interaction means of carcass characteristics, cutability, loin and chop quality, and bacon characteristics between sire line and sex

| | Pietrain | | Duroc | |
|---|---|---|---|---|
| Item | Barrow | Gilt | Barrow | Gilt |
| Pens, n | 20 | 20 | 20 | 20 |
| Overall G:F | 0.354[c] | 0.385[a] | 0.358[bc] | 0.368[b] |
| Whole shoulder % chilled side wt. | 21.03[b] | 21.51[a] | 21.50[a] | 21.21[ab] |
| Bone-in-Boston % chilled side wt. | 8.16[b] | 8.73[a] | 8.17[b] | 8.23[b] |
| Whole loin % chilled side wt. | 27.44[a] | 26.65[b] | 27.23[a] | 27.24[a] |
| Spareribs % chilled side wt. | 3.47[b] | 3.71[a] | 3.58[b] | 3.58[b] |
| Boneless Boston % chilled side wt. | 7.57[b] | 8.08[a] | 7.51[b] | 7.51[b] |
| Jowl, kg | 1.62[a] | 1.43[c] | 1.52[b] | 1.45[bc] |
| Boneless shoulder % chilled side wt. | 14.96[b] | 15.68[a] | 15.01[b] | 14.94[b] |
| Bone-in lean cutting yield, % | 56.49[b] | 58.98[a] | 56.19[b] | 56.85[b] |
| Early ventral loin pH | 5.53[b] | 5.53[b] | 5.61[a] | 5.54[b] |
| Early chop visual color | 3.10[b] | 3.23[ab] | 3.29[a] | 3.14[b] |
| Aged ventral loin pH | 5.58[c] | 5.59[bc] | 5.65[a] | 5.61[b] |
| Purge loss, % | 7.47[a] | 7.16[ab] | 6.55[b] | 7.39[a] |
| Belly thickness, cm | 4.24[a] | 3.70[c] | 4.30[a] | 4.04[b] |
| Slice yield (initial wt), % | 92.39[a] | 89.32[b] | 92.42[a] | 92.61[a] |
| Middle slice length, cm | 26.05[a] | 25.34[b] | 25.58[ab] | 25.75[ab] |
| Flank slice secondary lean area, $cm^2$ | 5.54[ab] | 5.85[ab] | 6.35[a] | 5.46[b] |
| Bacon percentage of lean, % | 48.10[b] | 52.02[a] | 48.90[b] | 48.07[b] |
| Bacon percentage of fat, % | 51.90[a] | 47.98[b] | 51.11[a] | 51.93[a] |
| Bacon lean:fat | 0.94[b] | 1.10[a] | 0.97[b] | 0.94[b] |

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## Chapter 4

## CORRELATION COMPARISONS AMONG EARLY POSTMORTEM LOIN QUALITY AND AGED LOIN AND PORK CHOP QUALITY CHARACTERISTICS BETWEEN FINISHING PIGS FROM EITHER DUROC OR PIETRAIN SIRES

### ABSTRACT

Today, the U.S. exports 2.2 million t of pork and pork products annually, representing just over 26% of U.S. pork production. In order to meet specific demands of a growing export market, pork quality and carcass characteristics are now integrated into breeding objectives. Color and marbling are two loin quality traits that influence consumer acceptability of pork and while correlations between early and aged ventral quality have been established, it is unclear if those correlations differ between production objectives (meat quality vs. lean growth). Therefore, the objective of this experiment was to compare correlations among early postmortem ventral loin quality characteristics and aged ventral loin and chop quality characteristics between pigs sired by either Pietrain (lean growth) or Duroc (meat quality) boars. Early postmortem (~1 d) quality traits included: instrumental and visual color, marbling and firmness, and loin pH on the ventral surface of the loin. Loins were aged until 14 d postmortem in vacuum packages. Aged quality traits included traits evaluated early as well as Warner-Bratzler shear force and cook loss. Correlations were compared between Pietrain and Duroc-sired pigs using a Fisher's z test. Early L* was moderately correlated with aged ventral L* (Pietrain $r = 0.47$; Duroc $r = 0.65$) and aged ventral visual color (Pietrain $r = 0.42$; Duroc $r = 0.58$). Early ventral visual color was moderately correlated with aged chop L* (Pietrain $r = 0.46$; Duroc $r = 0.60$) and aged chop visual color (Pietrain $r = 0.45$; Duroc $r = 0.57$). Early visual marbling was strongly correlated (Pietrain $r = 0.68$; Duroc $r = 0.84$) with aged chop visual marbling. Within the Duroc-sired pigs, early L* was

moderately correlated with aged chop L* (r = 0.64) but only weakly correlated (r = 0.35) within the Pietrain-sired pigs and those correlations differed at $P \leq 0.02$. Within the Duroc-sired pigs, early ventral visual color was moderately correlated with aged pH (r = 0.44) and aged ventral L* (r = 0.57) but only weakly correlated (r ≤ 0.29) within the Pietrain-sired pigs and those correlations differed at $P \leq 0.03$. No early postmortem quality traits were correlated (|r| ≤ 0.34) with WBSF or cook loss for either sire line. In summary, correlations between early and aged postmortem quality traits rarely differed between Duroc and Pietrain-sired pigs. It is not necessary to account for sire line when relating early and aged quality characteristics.
**Key words:** correlation, genotype, loin quality, pork, quality, sire line

## INTRODUCTION

Pork is the most consumed animal protein in the world and exported from the U.S. to countries such as Mexico, Japan, and China [United States Meat Export Federation (USMEF), 2017]. As of the end of 2017, the U.S. exported 2.45 million metric tons of pork and pork-related products annually, which represents just over 26% of U.S. pork production. Mexico and Japan represent two of the top markets for U.S. pork in 2017. Mexico imported the largest amount of pork (801,887 metric tons; $1.5 billion), but Japan was the largest importer on a value basis (393,648 metric tons; $1.6 billion, USMEF, 2017). Japanese importers rank eating quality as the second most important quality attribute (Murphy et al., 2015), but Mexican importers prefer a leaner product (Ngapo et al., 2017). Due to consumer differences in final product demands (color and marbling vs leanness), sophisticated breeding objectives are used in order to meet specific demands of a growing export market (Miar et al., 2014). Duroc-based breeds are often used to meet the needs of a quality focused market (NPPC, 1995), whereas Pietrain-based breeds are fast growing, lean pigs commonly used to satisfy the demand of a lean focused market (Edwards et al., 2003).

Even in lean-based export markets, eating quality of pork is important. Color and (marbling are two loin quality traits believed to influence the palatability of pork (Huff-Lonergan et al., 2002). Because the cut surface of a boneless pork loin is not exposed during the fabrication process (early postmortem), packers, use the ventral surface of loins during color and marbling evaluation to determine early postmortem pork quality. Recently, it was reported that correlations between early ventral quality and aged quality exist (Harsh et al., 2018) however, it is unclear if those correlations differ between pigs selected for lean growth compared with those selected for meat quality. Therefore, the objective of this study was to compare correlations among early postmortem loin quality characteristics and aged loin and chop quality characteristics between pigs sired by either Pietrain or Duroc boars.

## MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol for this experiment.

### *Pig Background*

Pigs (320 total) were sourced from two distinct sire lines, 160 barrows and gilts were Pietrain-sired pigs and 160 barrows and gilts were Duroc-sired pigs (Choice Genetics, West Des Moines, IA). Pietrain and Duroc boars were mated with Camborough (Pig Improvement Company, Hendersonville, TN) sows and parity was balanced among sire lines. Pigs were housed in pens of 4 pigs per pen (all from the same sire line) with all pigs within a pen of the same sex. A total of 80 pens of pigs were used in the experiment with 40 pens used in each of 2 blocks. A block was defined as a farrowing group. Pigs from block 1 were 2 weeks older than pigs in block 2. The Pietrain-sired pigs were classified as the lean growth line and the Duroc-sired pigs were classified as the meat quality line. Pigs were raised at the University of Illinois Swine Research Center and fed the same diet that met or exceeded nutrient requirements for growing-finishing pigs. A 3-phase, 98 d grow-finish feeding program was used. Day 98 for each block was considered the end of the feeding portion of the trial and all pigs were weighed in order to calculate growth characteristics. On d 98, the heaviest pig from each pen (40 pigs per block; 80 pigs total) was removed and transported to the University of Illinois Meat Science Laboratory (Urbana, IL) for slaughter on d 99. Also on d 99, the second heaviest and lightest pigs from each pen (80 pigs per block; 160 pigs total) were removed and transported to a federally inspected abattoir. These pigs were not used in the calculation of correlation coefficients. The remaining pig (third heaviest) was slaughtered at the University of Illinois Meat Science Laboratory on d 101 (40 pigs per block; 80 pigs total). In total, 160 of the 320 pigs were slaughtered at the University of Illinois Meat Science Laboratory and used to calculate correlation coefficients. Pigs were transported to the University of Illinois Meat Science Laboratory (Urbana, IL) and were held in lairage for approximately 16 h prior to slaughter. They were provided ad libitum access to water but had no access to feed during this time. Pigs were weighed immediately before slaughter to determine an ending live weight and were slaughtered under the supervision of the Food Safety and Inspection Service of the United States Department of Agriculture (**USDA**). Pigs were immobilized using head-to-heart electrical stunning and terminated via exsanguination. Carcasses were weighed approximately 45 min postmortem to determine hot carcass weight (**HCW**). Carcasses were chilled at 4°C for a minimum of 20 h. Early and aged loin quality evaluations were collected on 80 barrow carcasses and 80 gilt carcasses slaughtered on 4 different days.

***Abattoir Data Collection***

Estimates of carcass composition were determined on the left side of each carcass, which was separated between the $10^{th}$ and $11^{th}$ rib to expose the longissimus dorsi. Tenth-rib back fat thickness was measured at ¾ the distance of the longissimus dorsi from the dorsal process of the vertebral column. Loin muscle area was measured by tracing the cut surface of the longissimus dorsi on acetate paper. The longissimus dorsi tracings were measured in duplicate and the average of the two measurements was reported as loin muscle area. Standardized fat-free lean percentage was calculated using the equation (8.588 + (0.465 × HCW, lb) – (21.896 × fat thickness, in) + (3.005 × loin muscle area, $in^2$)) / HCW, lb) × 100 as described in procedure 1 for ribbed carcasses (Burson and Berg, 2001).

***Early Postmortem Pork Quality Evaluation***

The left side of each carcass was fabricated according to the North American Meat Processors and loin primal pieces were further fabricated into boneless Canadian back loins (NAMP #414). Day 1 loin weight (anterior and posterior portion) was recorded immediately following fabrication prior to early postmortem quality evaluation. Early postmortem quality measurements for instrumental color, visual color, visual marbling, subjective firmness, and ultimate pH were conducted by trained University of Illinois personnel. The cut surface of the longissimus dorsi, posterior to the $10^{th}$ rib, of each loin was re-surfaced and evaluated for quality parameters. Oxygenation of myoglobin on both the ventral and cut surface occurred at 4°C for approximately 20 minutes before quality measurements were evaluated. Brewer et al. (2001) reported that time of oxygen exposure from 0 min through 30 min had no effect on instrumental lightness (**L***) and instrumental redness (**a***) values did not change after 10 min of oxygen exposure. Therefore, 20 minutes was determined sufficient for oxygenation of myoglobin to occur. Instrumental L*, a*, and b* values (CIE 1978) were measured with a Minolta CR-400 Chroma meter (Minolta Camera Co., Ltd., Osaka, Japan) using a D65 light source, 2° observer angle, and 8 mm aperture calibrated using a white tile. Ultimate pH was measured on the ventral side of the longissimus dorsi muscle in the approximate location of the 10th rib using a Reed data logger, calibrated at 4°C, fitted with a Hanna glass electrode (REED SD-230 Series pH/ORP Datalogger, 0.00 to 14.00 pH/0-199 mV; Hanna FC200B electrode). Visual color and marbling scores (NPPC, 1999), and subjective firmness scores (NPPC, 1991) were determined by a single technician. After 1 d postmortem quality measures were complete, loins were vacuum packaged and aged for 13 d at 4°C.

***Aged Postmortem Loin Quality Evaluation:***

***Loin and Chop Quality***

At 14 d postmortem, loins were removed from the packaging, allowed to drip for approximately 20 minutes, and weighed. Purge loss (%) was calculated using the following equation:

*Purge Loss, % = [(1 d weight, kg – 14 d weight, kg) / 1 d weight, kg] ×100*

Loins were exposed to oxygen (fat side against the table and epimysium removed with the lean side up) for at least 20 min. Then quality measurements for instrumental color, visual color, visual marbling, subjective firmness, and aged ultimate pH were conducted on the ventral surface of the exposed lean using the same procedures as the 1 d postmortem quality evaluations using the manner described by Lowell et al. (2017). Ambient room temperature during evaluations was approximately 4°C. After quality evaluations were completed on the ventral surface of the loins, three loin chops from each loin were removed, posterior to the cut at the $10^{th}$ rib, for evaluation of proximate composition (moisture and extractable lipid), cook loss, and

Warner-Bratzler shear force (**WBSF**). Chops were sliced into 2.54 cm thick chops using a Bizerba deli slicer SE 12 D US (Bizerba USA Inc. Piscataway, NJ). Chop 1 was exposed to oxygen for at least 20 minutes before evaluation. Then, instrumental L*, a*, and b* values (CIE 1978) were measured with a Minolta CR-400 Chroma meter (Minolta Camera Co., Ltd., Osaka, Japan) using a D65 light source, 2° observer angle, and 8 mm aperture calibrated using a white tile. Visual color and marbling scores (NPPC, 1999), and subjective firmness scores (NPPC, 1991) were determined by a single technician. Chop 1 was then trimmed free of all subcutaneous fat and secondary muscles, packaged in Whirl-Pak bags (Nasco, Ft. Atkinson, WI), and stored at -20°C until determination of moisture and extractable lipid. Chop 2 was vacuum packaged and stored at -20°C until determination cook loss (%) and WBSF. Chop 3 was vacuum packaged and stored at -20°C as an archived sample.

***Cook Loss and Warner-Bratzler Shear Force***

The 2.54 cm thick chops were removed from the freezer at least 24 h prior to analysis and allowed to thaw thoroughly at approximately 1°C. Chops were individually weighed and then cooked on a Farberware Open Hearth grill (model 455N, Walter Kidde, Bronx, NY, USA). Chops were cooked, on one side, to an internal temperature of 31.5°C, flipped, and then cooked until they reached an internal temperature of 63°C, at which point they were removed. Internal temperature, during cooking, was monitored using copper-constantan thermocouples (Type T, Omega Engineering, Stamford, CT, USA) placed in the approximate geometric center of each chop and connected to a digital scanning thermometer (model 92000-00, Barnat Co, Barrington, IL). Chops were allowed to cool to approximately 25°C, and weighed again to determine percent cook loss. Five 1.25 cm diameter cores were removed parallel to the orientation of the muscle fibers and sheared using a Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, NY/Stable Mirosystems, Godalming, UK) with a blade speed of 3.33 mm/s and a load cell capacity of 100 kg. The shear force value for the 5 cores were averaged and the average was reported as WBSF.

***Proximate Composition***

Chops stored for analysis of moisture and extractable lipid were allowed to partially thaw, with great care taken to prevent loss of exudate. Samples were homogenized using a Cuisinart food processor (East Windsor, NJ). After homogenization, two 10-g samples from the homogenate were weighed and placed in a drying oven at 110˚C for at least 24 h. Samples were then weighed to determine moisture and washed multiple times in a mixture of chloroform and methanol for at least 8 h in the manner described by Novakofski et al. (1989). After extraction, samples were dried for at least 24 h before the lipid extracted weight was recorded.

***Statistical Analysis***

Early and late quality evaluations were compared within a loin from the same pig therefore, pig served as the experimental unit for all statistical analyses. Carcass and loin quality characteristics from both sire lines were compared using a 1-way ANOVA in the MIXED procedure of SAS 9.4 (SAS Inst. Inc. Cary, NC). The model included the fixed effect of sire line and the random effect of block. Differences in quality traits between Pietrain-sired pigs and Duroc-sired pigs were considered different at $P \leq 0.05$.

Comparisons of independent correlation coefficients between Pietrain-sired pigs and Duroc-sired pigs were achieved following the example of Kenny (1987) and Lowell et al. (2017) using a z-test for comparing two independent correlations. First, data were grouped into two individual data sets by sire line (Pietrain-sired pigs and Duroc-sired pigs). For each of these two data sets, Pearson correlations coefficients were calculated and transformed using the Fisher's r to z transformation with the FISHER option of the CORR procedure in SAS. The Fisher's r to z transformation was defined as:

$$z = \frac{1}{2} ln \left[\frac{1+r}{1-r}\right]$$

and used to ensure the transformed coefficients were nearly normally distributed and to make the variance of correlations approximately the same regardless of the value of the population correlation (Kenny, 1987). Where *r* is the Pearson correlation coefficient and *z* is the transformed value of the correlation coefficient.

If the *z* value was statistically significant, then the correlations between the two populations (Pietrain-sired pigs and Duroc-sired pigs) differ (Kenny, 1987). Next, Fisher's transformed *z* values were merged into a single data set and compared using the equation:

$$z = \frac{z_{Pietrain} - z_{Duroc}}{\sqrt{\frac{1}{n_{Pietrain} - 3} + \frac{1}{n_{Duroc} - 3}}}$$

Taylor (1990) cautions that correlation coefficients of 0.20 in data sets with more than 100 observations, like this data set, can be statistically different from 0 ($\alpha = 0.05$), but have little practical importance. Correlations were considered weak (in absolute value) at $r \leq 0.35$, correlations were considered moderate at $0.36 \leq r \leq 0.67$, and strong correlations were those $r \geq 0.68$ (Taylor, 1990). Therefore, differences in correlations of early and aged postmortem loin quality between Pietrain-sired pigs and Duroc-sired pigs were considered significant at $P \leq 0.05$ but must have had a correlation coefficient of $|r| \geq 0.36$ to be discussed as practically relevant.

## RESULTS

***Differences Between High Lean and High Quality Sire Lines for Early and Late Postmortem Quality Characteristics***

Ending live weight and HCW did not differ ($P \geq 0.66$, **Table 4.1**) between Duroc-sired and Pietrain-sired pigs. Duroc-sired pigs had a greater percent carcass yield ($P < 0.01$) and were fatter ($P < 0.001$) than the Pietrain-sired pigs. The Pietrain-sired pigs had a greater ($P < 0.01$) percent standardized fat free lean however, the two groups did not differ ($P \geq 0.85$) in loin eye area, loin weight, or loin weight as a percent of HCW (**Table 4.1**). Early postmortem ventral L* and a* were greater ($P < 0.01$) in loins from the Pietrain-sired pigs whereas early postmortem ventral visual marbling and ultimate pH were greater ($P < 0.01$) in loins from the Duroc-sired pigs. There were no other differences ($P \geq 0.07$) in early postmortem loin quality between the two groups.

Loins from the Duroc-sired pigs had greater aged postmortem ventral visual marbling ($P = 0.03$) and ultimate pH ($P < 0.001$) compared with loins from the Pietrain-sired pigs (**Table 4.2**). Aged postmortem ventral L*, a*, b*, visual color, subjective firmness, and percent purge did not differ ($P \geq 0.09$) between the Pietrain-sired pigs and Duroc-sired pigs.

Aged chop face visual marbling ($P < 0.001$) and percent extractable lipid ($P = 0.02$) were greater in loins from Duroc-sired pigs whereas loins from Pietrain-sired pigs had a greater ($P = 0.02$) percent moisture. Warner-Bratzler shear force values were greater ($P = 0.02$) for aged chops from Duroc-sired pigs compared with aged chops from Pietrain-sired pigs. There were no differences ($P \geq 0.06$) in aged chop L*, a*, b*, visual color, subjective firmness, or percent cook loss between the Pietrain-sired pigs and Duroc-sired pigs.

***Early Postmortem Ultimate pH***

Early ultimate pH was moderately correlated with aged pH (Pietrain, r = 0.56; Duroc, r = 0.52) and aged ventral b* (Pietrain, r = -0.45; Duroc, r = -0.37) within both groups of pigs (**Table 4.3**). Early ultimate pH was moderately correlated (r = -0.45) with aged ventral L* within the Duroc-sired pigs but only weakly correlated (r = -0.34) within the Pietrain-sired pigs. Early ultimate pH was moderately correlated (r = 0.43) with aged ventral visual color within the Duroc-sired pigs but only weakly correlated (r = 0.22) within the Pietrain-sired pigs. Early ultimate pH was moderately correlated (r = -0.44) with chop L* within the Duroc-sired pigs but only weakly correlated (r = -0.33) within the Pietrain-sired pigs. Early ultimate pH was moderately correlated (r = 0.43) with chop visual color within the Duroc-sired pigs but only weakly correlated (r = 0.34) within the Pietrain-sired pigs. However, these correlations did not differ ($P \geq 0.10$) between the Pietrain-sired pigs and Duroc-sired pigs. Early ultimate pH was not correlated with early ventral a*, early ventral visual marbling, early ventral subjective firmness, chop a*, chop b*, chop visual marbling, or chop subjective firmness in either the Pietrain-sired pigs or Duroc-sired pigs.

***Early Postmortem Ventral Instrumental Lightness (L*)***

Early ventral L* was moderately correlated to aged ventral pH (Pietrain, r = -0.40; Duroc, r = -0.52), aged ventral L* (Pietrain, r = 0.47; Duroc, r = 0.65), and aged ventral visual color (Pietrain, r = -0.42; Duroc, r = - 0.58) within both groups of pigs (**Table 4.4**). Early ventral L* was moderately correlated (r = -0.52) with chop color within the Duroc-sired pigs but only weakly correlated (r = -0.28) within the Pietrain-sired pigs. However, these correlations did not differ ($P \geq 0.08$) between the Pietrain-sired pigs and Duroc-sired pigs. Early L* was moderately correlated (r = 0.62) with aged ventral b* within the Duroc-sired pigs but only weakly correlated (r = 0.29) within the Pietrain-sired pigs and those correlations differed at *P* = 0.01. Early L* was moderately correlated (r = 0.64) with aged chop lightness within the Duroc-sired pigs but only weakly correlated (r = 0.35) within the Pietrain-sired pigs and those correlations differed at *P* = 0.02. Early L* was moderately correlated (r = 0.48) with aged chop b* within the Duroc-sired pigs but only weakly correlated (r = 0.28) within the Pietrain-sired pigs and those correlations difference at *P* = 0.02. Early L* was not correlated with aged ventral a*, aged ventral visual marbling, aged subjective firmness, aged chop a*, aged chop visual marbling, or aged chop subjective firmness in either the Pietrain-sired pigs or Duroc-sired pigs.

***Early Postmortem Ventral Instrumental Redness (a*) and Yellowness (b*)***

Early ventral a* was moderately correlated with aged chop a* (Pietrain, r = 0.51; Duroc, r = 0.51) and aged chop b* (Pietrain, r = 0.41; Duroc, r = 0.39) within both groups of pigs (**Table 4.5**). Early ventral a* was moderately correlated (r = 0.44) with aged ventral a* within the Pietrain-sired pigs but only weakly correlated (r = 0.33) within the Duroc-sired pigs. Early ventral a* was moderately correlated (r = 0.43) with aged ventral b* within the Pietrain-sired pigs but only weakly correlated (r = 0.24) within the Duroc-sired pigs. These correlations did not differ ($P \geq 0.17$) between the Pietrain-sired pigs and the Duroc-sired pigs. Early ventral a* was not correlated with aged loin pH, aged ventral L*, aged ventral visual color, aged ventral visual marbling, aged subjective firmness, aged chop L*, aged chop visual color, aged chop visual marbling, or aged chop subjective firmness in either of the two groups of pigs.

Early ventral b* was moderately correlated with aged ventral b* (Pietrain, r = 0.47; Duroc, r = 0.41) and aged chop b* (Pietrain r = 0.45; Duroc r = 0.45) within both groups of pigs (**Table 4.6**). Early ventral b* was moderately correlated (r = 0.45) with aged chop L* within the Duroc-sired pigs but only weakly correlated (r = 0.32) within the Pietrain-sired pigs. Early ventral b* was moderately correlated (r = -0.35) with chop visual color within the Duroc-sired pigs but only weakly correlated (r = -0.12) within the Pietrain-sired pigs. These correlations did not differ ($P \geq 0.13$) between the Pietrain-sired pigs and the Duroc-sired pigs. Early ventral b* was not correlated with aged loin pH, aged ventral a*, aged ventral visual color, aged ventral visual marbling, aged ventral subjective firmness, aged chop a*, aged chop visual marbling, or aged chop subjective marbling in either the Pietrain-sired pigs or Duroc-sired pigs.

***Early Postmortem Ventral Visual Color***

Early ventral visual color was strongly correlated (r = 0.73) with aged ventral visual color within the Duroc-sired pigs and moderately correlated (r = 0.63) within the Pietrain-sired pigs (**Table 4.7**). Early ventral visual color was also moderately correlated with aged chop L* (Pietrain, r = -0.46; Duroc, r = -0.60) and aged chop visual color (Pietrain, r = 0.45; Duroc, r = 0.57) within both groups of pigs. Early ventral visual color was moderately correlated (r = -0.39) with chop b* within the Duroc-sired pigs but only weakly correlated (r = -0.22) within the Pietrain-sired pigs. However, none of these correlations differed ($P \geq 0.24$) between the Pietrain-sired pigs and the Duroc-sired pigs. Early ventral visual color was moderately correlated (r = 0.44) with aged pH within the Duroc-sired pigs but only weakly correlated (r = 0.09) within the Pietrain-sired pigs and those correlations differed at $P = 0.02$. Early ventral visual color was moderately correlated (r = -0.57) with aged ventral L* within the Duroc-sired pigs but only weakly correlated (r = -0.29) within the Pietrain-sired pigs and those correlations differed at $P = 0.03$. Early ventral visual color was moderately correlated (r = -0.45) with aged ventral b* within the Duroc-sired pigs but only weakly correlated (r = -0.03) within the Pietrain-sired pigs and those correlations differed at $P = 0.01$. Early ventral visual color was not correlated to aged ventral visual marbling, aged ventral subjective firmness, aged chop a*, aged chop visual marbling, and aged chop subjective firmness in either the Pietrain-sired pigs or Duroc-sired pigs.

### *Early Postmortem Ventral Visual Marbling*

Early ventral visual marbling was moderately correlated with aged ventral visual marbling (Pietrain, r = 0.56; Duroc, r = 0.49) and strongly correlated with aged chop visual marbling (Pietrain, r = 0.68; Duroc, r = 0.84) within both groups of pigs (**Table 4.8**). Early ventral visual marbling was not correlated with any other aged loin and chop quality characteristics in either the Pietrain-sired pigs or Duroc-sired pigs.

### *Early Postmortem Quality Traits and Warner-Bratzler Shear Force and Cook Loss*

No early postmortem quality traits were correlated with WBSF or cook loss for either the Pietrain-sired pigs or Duroc-sired pigs (**Table 4.9**).

## DISCUSSION

Mexico imports the most U.S. pork on a total volume basis, but Japan is the greatest importer of U.S. pork on a total value basis (National Pork Board, 2017). Japanese importers prefer a darker, more highly marbled product, and Mexican importers prefer a high lean product (Murphy et al., 2015; Ngapo et al., 2017). The contrasting demands of these two export markets and similar demands within the U.S. market have resulted in the need for both lean growth and meat quality production focuses. As producers are faced with the challenge of meeting specific requirements of distinct markets (lean growth vs. meat quality), pork quality and carcass characteristics are now considered essential breeding objectives and integrated into many breeding programs (Miar et al., 2014). Based on genetic differences between breeds and genetic variation within breeds for meat quality traits, genetic changes in meat quality are possible through breed substitution and selection technologies (Cameron et al., 1999).

Historical differences in carcass characteristics and carcass yield between Duroc and Pietrain-sired pigs are well-documented (Affentrager et al., 1996; Ellis et al., 1996; Edwards et al., 2003) and results of this study reflect those of previous research. The Duroc breed is used extensively in production of crossbred market hogs because of its meat quality advantages (Schwab et al., 2006), and the Pietrain breed is commonly used to satisfy the demand for lean pork exported to Mexico (Edwards et al., 2003). In the present study, Duroc-sired pigs produced more highly marbled, meeting the demands of a quality export market. This is supported by previous research (Edwards et al., 2003) which also, more highly marbled loins from a meat quality sire line compared with a lean growth sire line. However, the meat quality traits between the 2 breeds did not differ to the magnitude expected based on historical data.

The ultimate goal of packer selection of high quality loins is to increase consumer satisfaction and therefore increase consumer purchases of product. Historically, meat quality traits such as visual color, visual marbling, and percent drip loss differ between meat quality and lean growth sire lines (Edwards et. al., 2003; Arkfeld et. al., 2016). These differences can influence selection for premium-based programs by the packer, as well as consumer purchase intent (Edwards et al., 2003; Lonergan et al., 2007; Moeller et al., 2010). While packers estimate quality on the ventral surface of a boneless loin after carcass fabrication, consumers often observe the cut surface of loin chops. Packers determine loin quality based on color and marbling on the ventral surface of loins during carcass fabrication at 1d postmortem (King et al., 2011). At this time, darker loins with more marbling are often selected for premium-based programs, many of which are exported to countries with a demand for high quality products (Holmer and Sutton, 2009, Lusk et al., 2017). This selection is possible as early postmortem quality characteristics and eating quality are correlated (Huff-Lonergan et al., 2002). Huff-Lonergan et al. (2002)

reported that loin pH at 24 h postmortem was weakly correlated to aged L* (r = - 0.32), aged ventral firmness (r = 0.20), cook loss (r = - 0.20), tenderness (r = 0.27), juiciness (r = 0.17), and flavor (r = 0.25). It has also been established that there are correlations between early postmortem loin quality characteristics and aged loin and chop quality characteristics, and these correlations largely do not differ between barrows and gilts (Lowell et al., 2017). Lowell et al. (2017) reported that Early postmortem (1 d) loin pH was strongly correlated with aged pH (r = 0.80 barrows; 0.75 gilts). Early pH was moderately correlated with aged ventral L* (r = - 0.57 barrows; - 0.54 gilts), aged subjective ventral color (r = 0.55 barrows; 0.41 gilts), and aged subjective chop color (r = 0.42 barrows; 0.44 gilts) (Lowell et al., 2017). Early ventral L* was moderately correlated with aged ventral L* (r = 0.60 barrows; 0.51 gilts) (Lowell et al., 2017). Early ventral visual marbling was moderately correlated with aged ventral visual marbling (r = 0.67 barrows; 0.66 gilts) and visual aged chop marbling (r = 0.57 barrows; 0.59 gilts) (Lowell et al., 2017). However, with the use of both meat quality and lean growth sire lines, to meet demands of varying export markets, correlations between early loin quality characteristics and aged loin and chop quality characteristics must also be established. Due to the established differences in meat quality between breeds characterized as meat quality and breeds characterized as lean growth, it was expected that correlations between early loin quality characteristics and aged loin and chop quality characteristics would differ between Duroc and Pietrain-sired pigs.

In the present study, loin pH at 1 d postmortem was correlated to aged ventral L* (Pietrain r = -0.35; Duroc r = -0.45), aged ventral visual color (Pietrain r = 0.22; Duroc r = 0.43), aged chop L* (Pietrain r = -0.33; Duroc r = -0.44), and aged chop visual color (Pietrain r = 0.34; Duroc r = 0.43). This is supported by previous research (Hamilton et al., 2003) which reported correlations of early loin pH with aged loin L* (r = -0.77). Another study, Huff-Lonergan et al. (2002), reported a correlation between pH and aged loin color (r = 0.30). However, both the study by Hamilton et al. (2003) and Huff-Lonergan et al. (2002) aged loins for approximately 48 h postmortem and therefore, may not accurately represent the quality traits observed by the consumer, which usually occurs after a longer aging period. The difference in time of aging may also explain the differences between the correlations observed in previous studies by Hamilton et al. (2003) and Huff-Lonergan et al. (2002) compared to correlations observed in the present study.

Correlations between early color and aged color were supported by the moderate correlation between early ventral L* and aged ventral visual color (Pietrain r = -0.42; Duroc r = -0.54). Lowell et al. (2017) also reported a correlation between early L* and aged ventral visual color (Barrows r = -0.39; Gilts r = -0.08). Previous research (Huff-Lonergan et al., 2002; Boler et al., 2010) also reported moderate to strong correlations between L* and visual color. Correlations between early L* and aged chop L*, and early visual color and aged L* differed between the Duroc-sired pigs and the Pietrain-sired pigs. It is possible that these differences are due to differences in muscle fiber type. Based on previous research, it could be concluded that correlation differences in early and aged color characteristics could be due an increase in glycolytic fibers within the Pietrain-sired pigs (Klont et. al., 1998). Intensive genetic selection for lean muscle growth, of the Pietrains, has likely caused a shift in fiber type composition, resulting in a greater proportion of glycolytic fibers and a reduced frequency of oxidative fibers (Klont et al., 1998). An increase in glycolytic fiber type tends to increase L* and decrease WHC whereas an increase in oxidative fiber type tends to decrease L*, increase a*, and increase WHC, resulting in a more visually appealing cut of meat (Klont et al., 1998; Joo et al., 2013). This difference in color could therefore be, in part, due to an increase in myoglobin associated with an increase in oxidative muscle fibers (Joo et. al.,2013). There was also a correlation between early ventral a* and aged chop a* yet previous work by Lowell et al. (2017) reported that correlations did not exist between early ventral a* and aged chop a*. The aforementioned differences in fiber types between Pietrain and Duroc pigs may explain the correlation between early ventral a* and aged chop a* observed in this present study. An increased proportion of oxidative fiber types, seen in Duroc pigs, often results in a darker, more red loin (Joo et al., 2013). Differences in mean pH between sire lines could also be explained by the differences in muscle fiber type. A greater amount of glycolytic fibers decreases pH through rapid glycolysis and accumulation of lactate (Choi et. al., 2006). Even so, the differences in pH were not great enough to influence correlations between early pH and aged pork quality traits. Another explanation for the correlation differences, observed in this study, between sire lines could be the increased variability in the Duroc-sired pigs. A study by Arkfeld et al. (2017) also reported that pigs destined for a quality-focused market were more variable compared with pigs destined for a lean-focused market.

The ultimate goal of selecting loins based on quality characteristics in the early postmortem period is to segregate loins into categories that provide an expected eating experience. Tenderness is often cited as the most important for consumer eating experience (Moeller et al., 2010). Based on this, correlations between early postmortem quality characteristics and tenderness are important. It should be noted that the loin chops from the Pietrain-sired pigs were actually more tender than chops from the Duroc-sired pigs. However, the magnitude of difference was not great enough to influence correlations between early postmortem quality and tenderness, and chops from both groups of pigs would be considered tender. Previous work has also reported no correlations between instrumental or visual color parameters and instrumental or sensory tenderness (Harsh et al. 2018).

Moderate correlations between early ventral visual marbling and aged ventral visual marbling as well as strong correlations between early ventral visual marbling and aged chop visual marbling, within both sire lines, indicate that early postmortem estimates of marbling, on the ventral surface, are correlated with aged estimates of marbling. However, early ventral visual marbling was not correlated with WBSF in meat quality or lean growth sire lines. Wilson et al. (2017) reported that extractable lipid (range 0.80% to 5.52%) explained less than 1% of the variation in sensory tenderness of pork loin chops cooked to a medium-rare degree of doneness (63ºC). Additionally, Rincker et al. (2008) reported that extractable lipid (range 0.76% to 8.09%) did not influence instrumental or sensory tenderness of pork loins cooked to a medium (71ºC) degree of doneness.

Unlike beef carcasses, pork carcasses are not usually ribbed (cut between the $10^{th}$ and $11^{th}$ rib to expose the longissimus muscle) in the U.S. The amount of epimysium left on the ventral surface of a pork loin during fabrication can affect what portion (anterior or posterior) of the ventral surface is visible for color evaluation. Several studies have observed that color is not consistent between the anterior and posterior ends of the longissimus muscle (Van Oeckel and Warnants, 2003; Homm et. al., 2006). Due to differences in color between the anterior and posterior ends of the longissimus muscle, it is important to be consistent when evaluating color quality on the ventral surface.

Based on the results of the present study it may be possible to use early L* and ventral visual color as indicators of aged chop color. Additionally, early ventral visual marbling could be used to estimate marbling in both aged loins and aged loin chops. The majority of correlation comparisons did not differ between Duroc and Pietrain-sired pigs however, there were some early postmortem quality characteristics that were correlated in the Duroc-sired pigs but not the Pietrain-sired pigs, most likely due to the afore mentioned quality differences between the two breed types. While there were differences between Duroc and Pietrain-sired pigs in terms of quality characteristics, the majority of correlations between early and aged quality did not differ between the two sire lines. Therefore, the same early postmortem quality traits can be used to predict aged quality regardless of sire line. Additionally, it is not necessary to account for sire line when using early postmortem quality traits to estimate aged quality observed by the consumer.

## TABLES

**Table 4.1.** Carcass characteristics and early postmortem meat quality traits of Pietrain and Duroc-sired pigs collected on the ventral side of the longissimus muscle

| | Sire | | | |
|---|---|---|---|---|
| Item | Pietrain | Duroc | SEM | *P* - Value |
| Pigs, n | 80 | 80 | | |
| Carcass characteristics | | | | |
| Ending live wt, kg | 130.87 | 130.69 | 3.28 | 0.88 |
| Hot carcass wt, kg | 103.20 | 103.66 | 2.58 | 0.66 |
| Carcass yield, % | 78.82 | 79.31 | 0.12 | < 0.01 |
| $10^{th}$ rib fat thickness, cm | 1.60 | 1.93 | 0.14 | < 0.001 |
| Loin muscle area, cm | 55.58 | 55.40 | 0.98 | 0.85 |
| Standardized fat-free lean, %[1] | 55.76 | 54.36 | 0.71 | < 0.001 |
| Canadian back loin (NAMP #414) wt, kg | 3.86 | 3.87 | 0.09 | 0.93 |
| % chilled carcass wt | 7.52 | 7.50 | 0.07 | 0.89 |
| Early postmortem ventral quality traits | | | | |
| Instrumental color[2] | | | | |
| Lightness, L* | 48.33 | 48.09 | 0.86 | 0.60 |
| Redness, a* | 10.10 | 10.01 | 0.61 | 0.69 |
| Yellowness, b* | 3.52 | 3.13 | 0.46 | 0.07 |
| Subjective evaluations[3] | | | | |
| Visual color score | 3.43 | 3.44 | 0.06 | 0.88 |
| Visual marbling score | 1.76 | 2.15 | 0.14 | < 0.01 |
| Firmness score | 3.64 | 3.56 | 0.05 | 0.21 |
| Ventral loin pH[4] | 5.53 | 5.57 | 0.02 | < 0.001 |

[1]Standardized fat-free lean = ((8.588 + (0.465 × HCW, lb) – (21.896 × fat depth, in) + (3.005 × longissimus thoracis area, $in^2$))/HCW) × 100, (Burson and Berg, 2001).

[2]L* measures darkness to lightness (greater L* indicates a lighter color), a* measures redness (greater a* indicates a redder color), b* measures yellowness (greater b* indicates a more yellow color)

[3]Evaluations based on NPPC 1991 and 1999 standards where 1 = visually palest color, and 6 = visually darkest color; where 1 = visually the least marbling and 6 = visually the most marbling; and where 1 = softest and 6 = firmest.

[4]Loin pH was measured on the ventral surface of the boneless loins at the area of the 10th rib

**Table 4.2.** Aged postmortem (14 d) meat quality traits of Duroc- and Pietrain sired pigs collected on the ventral side or chop face of the longissimus muscle

| | Sire | | | |
|---|---|---|---|---|
| Item | Pietrain | Duroc | SEM | *P* – value |
| Pigs, n | 80 | 80 | | |
| *Ventral* | | | | |
| Instrumental color[1] | | | | |
| Lightness, L* | 50.19 | 49.61 | 0.35 | 0.19 |
| Redness, a* | 10.49 | 10.61 | 0.28 | 0.58 |
| Yellowness, b* | 5.09 | 4.80 | 0.33 | 0.15 |
| Subjective evaluations[2] | | | | |
| Visual color score | 3.29 | 3.42 | 0.09 | 0.09 |
| Visual marbling score | 2.16 | 2.39 | 0.17 | 0.03 |
| Subjective firmness score | 3.70 | 3.71 | 0.04 | 0.82 |
| Ultimate pH | 5.58 | 5.63 | 0.03 | < 0.001 |
| Aged loin wt, kg | 3.58 | 3.60 | 0.09 | 0.72 |
| Purge loss[3], % | 7.31 | 6.97 | 0.19 | 0.20 |
| *Chop* | | | | |
| Instrumental color[1] | | | | |
| Lightness, L* | 52.22 | 51.79 | 0.58 | 0.42 |
| Redness, a* | 9.90 | 10.04 | 0.27 | 0.46 |
| Yellowness, b* | 4.50 | 4.43 | 0.36 | 0.75 |
| Subjective evaluations | | | | |
| Visual color score | 3.21 | 3.32 | 0.05 | 0.07 |
| Visual marbling score | 2.04 | 2.68 | 0.10 | < 0.001 |
| Subjective firmness score | 3.08 | 3.15 | 0.07 | 0.19 |
| Moisture, % | 73.04 | 72.65 | 0.16 | 0.02 |
| Extractable lipid, % | 3.14 | 3.56 | 0.14 | 0.02 |
| Warner-Bratzler shear force[4], kg | 2.25 | 2.40 | 0.09 | 0.02 |
| Cook loss[5], % | 20.08 | 20.73 | 1.04 | 0.06 |

[1]L* measures darkness to lightness (greater L* indicates a lighter color), a* measures redness (greater a* indicates a redder color), b* measures yellowness (greater b* indicates a more yellow color).

[2]Evaluations based on NPPC 1991 and 1999 standards where 1 = visually palest color, and 6 = visually darkest color; where 1 = visually the least marbling and 6 = visually the most marbling; and where 1 = softest and 6 = firmest.

[3]Purge loss = [(1 d weight, kg – 14 d weight, kg) / 1 d weight, kg] ×100

[4]Chops used for Warner-Bratzler shear force were cooked to an internal temperature of 63°C.

[5]Cook loss = [(initial weight, kg – cooked weight, kg) / initial weight, kg] ×100. Chops were cooked to an internal temperature of 63°C.

**Table 4.3.** Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem loin pH values with aged loin quality and chop quality of Pietrain and Duroc-sired pigs[1,2]

| | Pietrain pH | | | Duroc pH | | | |
|---|---|---|---|---|---|---|---|
| | | 95% Confidence limit | | | 95% Confidence limit | | |
| Aged postmortem variable | Rho | Lower | Upper | Rho | Lower | Upper | *P* - value[3] |
| *Loin* | | | | | | | |
| Loin pH | 0.56 | 0.38 | 0.69 | 0.52 | 0.33 | 0.66 | 0.74 |
| Ventral lightness, L* | -0.34 | -0.52 | -0.13 | -0.45 | -0.61 | -0.25 | 0.44 |
| Ventral redness, a* | -0.16 | -0.37 | 0.06 | 0.11 | -0.12 | 0.32 | 0.10 |
| Ventral yellowness, b* | -0.45 | -0.61 | -0.25 | -0.37 | -0.54 | -0.16 | 0.54 |
| Visual color | 0.22 | -0.01 | 0.42 | 0.43 | 0.23 | 0.59 | 0.14 |
| Visual marbling | 0.25 | 0.03 | 0.45 | 0.27 | 0.05 | 0.47 | 0.89 |
| Subjective firmness | 0.05 | -0.17 | 0.27 | 0.01 | -0.21 | 0.24 | 0.82 |
| *Chop* | | | | | | | |
| Lightness, L* | -0.33 | -0.51 | -0.12 | -0.44 | -0.61 | -0.24 | 0.40 |
| Redness, a* | -0.20 | -0.40 | 0.03 | -0.17 | -0.38 | 0.06 | 0.87 |
| Yellowness, b* | -0.35 | -0.53 | -0.14 | -0.34 | -0.52 | -0.12 | 0.92 |
| Visual color | 0.34 | 0.13 | 0.52 | 0.43 | 0.24 | 0.60 | 0.50 |
| Visual marbling | 0.05 | -0.17 | 0.27 | 0.24 | 0.02 | 0.44 | 0.22 |
| Subjective firmness | -0.08 | -0.29 | 0.14 | -0.02 | -0.24 | 0.21 | 0.69 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]Aged postmortem traits were evaluated 14 d postmortem

[3]Probablity value comparing correlation coefficients of meat quality traits between Pietrain and Duroc-sired pigs

**Table 4.4.** Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem instrumental lightness (L*) values with aged loin quality and chop quality of Pietrain and Duroc-sired pigs[1,2]

| | Pietrain L* | | | Duroc L* | | | |
|---|---|---|---|---|---|---|---|
| | | 95% Confidence limit | | | 95% Confidence limit | | |
| Aged postmortem variable | Rho | Lower | Upper | Rho | Lower | Upper | *P* - value[3] |
| *Loin* | | | | | | | |
| Loin pH | -0.40 | -0.57 | -0.19 | -0.52 | -0.67 | -0.34 | 0.32 |
| Ventral lightness, L* | 0.47 | 0.28 | 0.63 | 0.65 | 0.50 | 0.76 | 0.10 |
| Ventral redness, a* | 0.00 | -0.22 | 0.22 | 0.17 | -0.05 | 0.38 | 0.29 |
| Ventral yellowness, b* | 0.29 | 0.08 | 0.48 | 0.62 | 0.46 | 0.74 | 0.01 |
| Visual color | -0.42 | -0.58 | -0.22 | -0.58 | -0.71 | -0.41 | 0.18 |
| Visual marbling | 0.14 | -0.08 | 0.35 | -0.25 | -0.44 | -0.03 | 0.02 |
| Subjective firmness | -0.06 | -0.27 | 0.17 | 0.14 | -0.09 | 0.34 | 0.24 |
| *Chop* | | | | | | | |
| Lightness, L* | 0.35 | 0.14 | 0.53 | 0.64 | 0.49 | 0.76 | 0.02 |
| Redness, a* | 0.02 | -0.20 | 0.24 | 0.22 | 0.00 | 0.42 | 0.22 |
| Yellowness, b* | 0.15 | -0.07 | 0.36 | 0.48 | 0.29 | 0.64 | 0.02 |
| Visual color | -0.28 | -0.47 | -0.07 | -0.52 | -0.66 | -0.34 | 0.08 |
| Visual marbling | 0.09 | -0.13 | 0.30 | -0.07 | -0.28 | 0.15 | 0.33 |
| Subjective firmness | 0.05 | -0.17 | 0.27 | 0.10 | -0.13 | 0.31 | 0.79 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]Aged postmortem traits were evaluated 14 d postmortem

[3]Probablity value comparing correlation coefficients of meat quality traits between Pietrain and Duroc-sired pigs

**Table 4.5.** Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem instrumental redness (a*) values with aged loin quality and chop quality of Pietrain and Duroc-sired pigs[1,2]

| | Pietrain a* | | | Duroc a* | | | |
|---|---|---|---|---|---|---|---|
| | | 95% Confidence limit | | | 95% Confidence limit | | |
| Aged postmortem variable | Rho | Lower | Upper | Rho | Lower | Upper | *P* - value[3] |
| *Loin* | | | | | | | |
| Loin pH | 0.00 | -0.22 | 0.22 | 0.11 | -0.11 | 0.33 | 0.49 |
| Ventral lightness, L* | -0.04 | -0.26 | 0.18 | 0.01 | -0.22 | 0.23 | 0.77 |
| Ventral redness, a* | 0.44 | 0.25 | 0.61 | 0.33 | 0.12 | 0.51 | 0.41 |
| Ventral yellowness, b* | 0.43 | 0.23 | 0.59 | 0.24 | 0.02 | 0.43 | 0.17 |
| Visual color | 0.09 | -0.13 | 0.31 | 0.03 | -0.19 | 0.25 | 0.71 |
| Visual marbling | -0.04 | -0.26 | 0.18 | 0.22 | 0.00 | 0.42 | 0.10 |
| Subjective firmness | -0.04 | -0.26 | 0.18 | 0.20 | -0.03 | 0.40 | 0.14 |
| *Chop* | | | | | | | |
| Lightness, L* | 0.11 | -0.12 | 0.32 | 0.23 | 0.01 | 0.43 | 0.43 |
| Redness, a* | 0.51 | 0.33 | 0.66 | 0.51 | 0.32 | 0.65 | 0.97 |
| Yellowness, b* | 0.41 | 0.21 | 0.58 | 0.39 | 0.18 | 0.56 | 0.89 |
| Visual color | 0.11 | -0.11 | 0.32 | -0.05 | -0.27 | 0.17 | 0.33 |
| Visual marbling | 0.03 | -0.19 | 0.25 | 0.32 | 0.10 | 0.50 | 0.06 |
| Subjective firmness | -0.17 | -0.38 | 0.05 | -0.10 | -0.32 | 0.12 | 0.68 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]Aged postmortem traits were evaluated 14 d postmortem

[3]Probablity value comparing correlation coefficients of meat quality traits between Pietrain and Duroc-sired pigs

**Table 4.6.** Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem instrumental yellowness (b*) values with aged loin quality and chop quality of Pietrain and Duroc-sired pigs[1,2]

| | Pietrain b* | | | Duroc b* | | | |
|---|---|---|---|---|---|---|---|
| | | 95% Confidence limit | | | 95% Confidence limit | | |
| Aged postmortem variable | Rho | Lower | Upper | Rho | Lower | Upper | *P* - value[3] |
| *Loin* | | | | | | | |
| Loin pH | -0.01 | -0.23 | 0.21 | -0.12 | -0.33 | 0.10 | 0.50 |
| Ventral lightness, L* | 0.22 | 0.00 | 0.42 | 0.35 | 0.14 | 0.53 | 0.37 |
| Ventral redness, a* | 0.23 | 0.01 | 0.42 | 0.20 | -0.02 | 0.40 | 0.87 |
| Ventral yellowness, b* | 0.47 | 0.28 | 0.62 | 0.41 | 0.21 | 0.58 | 0.64 |
| Visual color | -0.16 | -0.37 | 0.06 | -0.25 | -0.45 | -0.04 | 0.55 |
| Visual marbling | 0.15 | -0.08 | 0.36 | 0.11 | -0.12 | 0.32 | 0.80 |
| Subjective firmness | -0.05 | -0.27 | 0.17 | 0.20 | -0.02 | 0.40 | 0.12 |
| *Chop* | | | | | | | |
| Lightness, L* | 0.32 | 0.11 | 0.51 | 0.45 | 0.26 | 0.61 | 0.34 |
| Redness, a* | 0.34 | 0.13 | 0.52 | 0.34 | 0.13 | 0.52 | 1.00 |
| Yellowness, b* | 0.45 | 0.25 | 0.61 | 0.45 | 0.26 | 0.61 | 0.96 |
| Visual color | -0.12 | -0.33 | 0.10 | -0.35 | -0.53 | -0.14 | 0.13 |
| Visual marbling | 0.11 | -0.11 | 0.33 | 0.25 | 0.03 | 0.44 | 0.40 |
| Subjective firmness | -0.27 | -0.46 | -0.05 | -0.05 | -0.26 | 0.18 | 0.15 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]Aged postmortem traits were evaluated 14 d postmortem

[3]Probablity value comparing correlation coefficients of meat quality traits between Pietrain and Duroc-sired pigs

**Table 4.7.** Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem visual color values with aged loin quality and chop quality of Pietrain and Duroc-sired pigs[1,2]

| | Pietrain color | | | Duroc color | | | |
|---|---|---|---|---|---|---|---|
| | | 95% Confidence limit | | | 95% Confidence limit | | |
| Aged postmortem variable | Rho | Lower | Upper | Rho | Lower | Upper | *P* - value[3] |
| *Loin* | | | | | | | |
| Loin pH | 0.09 | -0.13 | 0.31 | 0.44 | 0.24 | 0.60 | 0.02 |
| Ventral lightness, L* | -0.29 | -0.48 | -0.07 | -0.57 | -0.70 | -0.40 | 0.03 |
| Ventral redness, a* | 0.27 | 0.05 | 0.46 | 0.10 | -0.13 | 0.31 | 0.27 |
| Ventral yellowness, b* | -0.03 | -0.24 | 0.20 | -0.45 | -0.61 | -0.25 | 0.01 |
| Visual color | 0.63 | 0.48 | 0.75 | 0.73 | 0.61 | 0.82 | 0.25 |
| Visual marbling | -0.14 | -0.35 | 0.09 | 0.32 | 0.10 | 0.50 | < 0.01 |
| Subjective firmness | 0.16 | -0.07 | 0.36 | 0.10 | -0.13 | 0.31 | 0.69 |
| *Chop* | | | | | | | |
| Lightness, L* | -0.46 | -0.62 | -0.27 | -0.60 | -0.72 | -0.43 | 0.24 |
| Redness, a* | 0.11 | -0.11 | 0.33 | -0.06 | -0.27 | 0.17 | 0.30 |
| Yellowness, b* | -0.22 | -0.42 | 0.00 | -0.39 | -0.56 | -0.19 | 0.24 |
| Visual color | 0.45 | 0.25 | 0.61 | 0.57 | 0.40 | 0.70 | 0.32 |
| Visual marbling | 0.00 | -0.22 | 0.22 | 0.22 | -0.01 | 0.42 | 0.17 |
| Subjective firmness | -0.11 | -0.32 | 0.12 | -0.02 | -0.24 | 0.20 | 0.58 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]Aged postmortem traits were evaluated 14 d postmortem

[3]Probablity value comparing correlation coefficients of meat quality traits between Pietrain and Duroc-sired pigs

**Table 4.8.** Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem visual marbling values with aged loin quality and chop quality of Pietrain and Duroc-sired pigs[1,2]

| | Pietrain marbling | | | Duroc marbling | | | |
|---|---|---|---|---|---|---|---|
| | | 95% Confidence limit | | | 95% Confidence limit | | |
| Aged postmortem variable | Rho | Lower | Upper | Rho | Lower | Upper | *P* - value[3] |
| *Loin* | | | | | | | |
| Loin pH | 0.23 | 0.01 | 0.43 | 0.29 | 0.07 | 0.48 | 0.26 |
| Ventral lightness, L* | 0.11 | -0.12 | 0.32 | -0.11 | -0.32 | 0.11 | 0.09 |
| Ventral redness, a* | -0.06 | -0.27 | 0.17 | 0.11 | -0.11 | 0.32 | 0.42 |
| Ventral yellowness, b* | 0.10 | -0.13 | 0.31 | -0.04 | -0.25 | 0.19 | 0.27 |
| Visual color | 0.03 | -0.19 | 0.25 | 0.12 | -0.10 | 0.33 | 0.39 |
| Visual marbling | 0.56 | 0.39 | 0.70 | 0.49 | 0.30 | 0.64 | 0.61 |
| Subjective firmness | 0.10 | -0.12 | 0.31 | 0.33 | 0.12 | 0.51 | 0.62 |
| *Chop* | | | | | | | |
| Lightness, L* | 0.01 | -0.21 | 0.23 | 0.02 | -0.21 | 0.24 | 0.91 |
| Redness, a* | 0.10 | -0.13 | 0.31 | 0.23 | 0.01 | 0.43 | 0.95 |
| Yellowness, b* | 0.17 | -0.05 | 0.38 | 0.18 | -0.05 | 0.38 | 0.95 |
| Visual color | 0.12 | -0.10 | 0.33 | 0.14 | -0.08 | 0.35 | 0.86 |
| Visual marbling | 0.68 | 0.55 | 0.79 | 0.84 | 0.77 | 0.90 | 0.93 |
| Subjective firmness | 0.11 | -0.12 | 0.32 | 0.02 | -0.20 | 0.24 | 0.30 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]Aged postmortem traits were evaluated 14 d postmortem

[3]Probablity value comparing correlation coefficients of meat quality traits between Pietrain and Duroc-sired pigs

**Table 4.9.** Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem loin quality traits between Pietrain and Duroc-sired pigs with Warner-Bratzler shear force (**WBSF**) and cook loss[1,2]

| | Pietrain | | | Duroc | | | |
|---|---|---|---|---|---|---|---|
| | | 95% Confidence limit | | | 95% Confidence limit | | |
| Early postmortem variable | Rho | Lower | Upper | Rho | Lower | Upper | *P* - value[3] |
| *WBSF* | | | | | | | |
| Loin pH | 0.00 | -0.22 | 0.22 | 0.04 | -0.19 | 0.26 | 0.84 |
| Ventral lightness, L* | 0.06 | -0.16 | 0.28 | -0.09 | -0.31 | 0.13 | 0.35 |
| Ventral redness, a* | -0.06 | -0.27 | 0.17 | 0.07 | -0.16 | 0.28 | 0.45 |
| Ventral yellowness, b* | -0.16 | -0.37 | 0.06 | -0.05 | -0.27 | 0.17 | 0.49 |
| Ventral color | 0.14 | -0.08 | 0.35 | 0.09 | -0.13 | 0.30 | 0.76 |
| Ventral marbling | -0.10 | -0.31 | 0.12 | -0.20 | -0.40 | 0.02 | 0.54 |
| Ventral firmness | 0.05 | -0.17 | 0.27 | -0.06 | -0.27 | 0.16 | 0.51 |
| *Cook Loss, %* | | | | | | | |
| Loin pH | -0.34 | -0.52 | -0.13 | -0.21 | -0.41 | 0.02 | 0.37 |
| Ventral lightness, L* | 0.08 | -0.14 | 0.30 | 0.19 | -0.03 | 0.40 | 0.49 |
| Ventral redness, a* | 0.15 | -0.07 | 0.36 | 0.03 | -0.19 | 0.25 | 0.45 |
| Ventral yellowness, b* | 0.15 | -0.07 | 0.36 | 0.05 | -0.17 | 0.27 | 0.55 |
| Ventral color | -0.13 | -0.34 | 0.10 | -0.11 | -0.32 | 0.11 | 0.92 |
| Ventral marbling | -0.19 | -0.39 | 0.03 | -0.30 | -0.49 | -0.09 | 0.47 |
| Ventral firmness | -0.17 | -0.38 | 0.05 | -0.02 | -0.24 | 0.20 | 0.36 |

[1]Early postmortem traits were evaluated 1 d postmortem

[2]Chops for Warner-Bratzler shear force and cook loss were aged for 14 d postmortem prior to analyses

[3]Probablity value comparing correlation coefficients of meat quality traits between Pietrain and Duroc-sired pigs

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